The SuDS Manual

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Flood and Coastal Erosion Risk Management R&D

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The SuDS Manual

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The SuDS Manual

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Sustainable drainage, flood risk management, water quality, amenity, biodiversity, environmental good practice, sustainable construction, urban hydrogeology, rivers and waterways		
Reader interest	**Classification**	
Sustainable drainage systems (SuDS) are designed to maximise the opportunities and benefits we obtain from surface water management. SuDS can deliver four main benefits by improving the way we manage water quantity, water quality, amenity and biodiversity	Availability	Unrestricted
	Content	Technical guidance
	Status	Committee-guided
	User	Developers, landscape architects, architects, consulting engineers, planners, local authorities, lead local flood authorities, highway authorities, environmental regulators, sewerage undertakers and other organisations involved in the provision and maintenance of surface water drainage to new and existing developments

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Summary

This guidance covers the planning, design, construction and maintenance of Sustainable Drainage Systems (SuDS) to assist with their effective implementation within both new and existing developments. It looks at how to maximise amenity and biodiversity benefits, and deliver the key objectives of managing flood risk and water quality. There is also supporting information covering topics such as materials, landscape design, maintenance, community engagement and costs and benefits.

The information presented in this publication is a compendium of good practice, based on existing guidance and research both in the UK and internationally, and the practical experience of the authors, project steering group and industry.

This guidance provides the framework for designing SuDS with confidence and to maximise benefits. Its contents are relevant for a wide-range of professions and roles and it highlights that through engagement and collaboration SuDS can be integrated into the design of urban areas, to create high quality places for future generations.

The key message is that SuDS should be designed to maximise the opportunities and benefits that can be secured from surface water management.

Foreword

When the first SuDS Manual was published in 2007, SuDS was still in its infancy in the UK. Technical advice on design and construction was sparse and spread across many separate publications. For the first time the original SuDS Manual placed this information in one place, making it a valuable resource for anyone engaged in SuDS delivery. Yet for guidance and examples we still had to rely a great deal on schemes from other countries where the implementation of SuDS was far more advanced. Since that time SuDS implementation has moved on a great deal in the UK. There are now plenty of examples from all the UK nations that demonstrate the benefits to be gained from SuDS and these offer reliable and detailed recommendations for their planning, design, construction, maintenance and operation. The world of SuDS has indeed moved on. So it is timely that a new edition of the SuDS Manual is now available. Not only does this new edition update the extensive technical information, it includes new guidance on SuDS components and the delivery of SuDS in a variety of situations.

It should be clear from the engaging examples in this Manual that SuDS provide real benefits to society and to the environment, moving surface water from a problem to a valuable resource. For the first time the guidance includes how to plan for and manage extreme rain events so that communities can be more resilient to flooding. There are some excellent examples that demonstrate how good design can deliver far more appealing places in which to live and work, and this, in time, should lead to properties that have improved value and are easier to insure. Provided that drainage is considered early enough in the outline design of a new development then there is no reason why SuDS should not become the norm everywhere.

The Manual is primarily aimed at UK applications, though it will be of interest to all engaged in drainage work globally. It recognises the need for better information and engagement for those involved in the development process, from planners, landscape architects, designers, engineers, architects and in some instances the community. It is structured in a way that allows easy access whether it be for high level appreciation of the concepts only, or for detailed design guidance.

I am grateful to the members of the project steering group who reviewed and contributed to this important work, and to the energy and effectiveness of the project team. They have delivered a master-piece of technical guidance that will last for many years. I thoroughly recommend it to you.

David Balmforth
Chairman, project steering group

Acknowledgements

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Steve is technical director of the Environmental Protection Group Limited. He is a UK registered ground engineering adviser and has had a wide ranging career in geotechnical and environmental engineering. Steve has demonstrated that SuDS can be used on any site in the UK to provide cost-effective surface water drainage systems. Steve also undertakes research and development work that helps to dispel a lot of the myths that surround the use of SuDS. Most recently Steve has been busy helping landscape architects successfully design retrofit schemes in a number of different locations.

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Helen is a principal engineer at HR Wallingford. She has more than 20 years' experience in drainage, flood and climate change risk assessments, with a particular interest in the development of guidance and working with stakeholders.

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Sue is managing director of Illman Young, a landscape architectural practice based in Cheltenham, and was president of the Landscape Institute from 2012–2014. Sue's practice works across most planning and development sectors, but she is probably best known for her advocacy work promoting integrated water management and SuDS through inter-professional collaboration. The integration of grey, green and blue in urban landscapes has never been more relevant, and is a subject that Sue continues to promote. In addition to her current role, she is a champion for flood mitigation and resilience on behalf of the Construction Industry Council (CIC).

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Tamasine is a landscape architect and senior associate of Grant Associates. She has led a variety of large and small projects, from cooled conservatories and university campuses in Singapore to secondary schools in the UK and urban parks in Spain. SuDS has become second nature in her design process, integrating the functional requirements of water management within playful and thriving landscapes. Tamsine is fascinated by using SuDS in the design process to integrate landscape, architecture and engineering, thereby achieving diverse landscapes that ultimately enrich experience.

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Permavoid
Polypipe
Scottish Environment Protection Agency
Stormwater Management
WSP Parsons Brinckerhoff
XP Solutions

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The SuDS Manual

Everyone with an interest in SuDS

Those responsible for policy or decision making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS Manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

A

Audience:
Everyone with an interest in SuDS
Those responsible for policy or decision making
Those responsible for delivering and managing a SuDS scheme

Introduction to the SuDS Manual

Image courtesy Kent County Council

Image courtesy Ben Luxmoore

INTRODUCTION TO THE SUDS MANUAL

Contents

Executive summary

WHY SUDS?

Surface water should be managed for maximum benefit, now and in the future. By working together we can integrate surface water management into the design of our towns and cities, protecting our environment and creating high quality places for future generations.

Why is managing surface water runoff so important?

When rain falls on a natural landscape, it soaks into the ground (infiltration), evaporates, is taken up by plants (evapotranspiration) and some of it eventually finds its way into streams and rivers.

These stages of the water cycle can be impeded when land is altered by development. In urban areas, there tends to be less permeable ground available for infiltration and less vegetation for evapotranspiration. When rain falls on impermeable surfaces, much more of it turns into surface water runoff, which can cause flooding, pollution and erosion problems.

Research shows that, if we don't change the way that we design our urban areas and manage surface water runoff more effectively, these problems are going to get worse. Climate change projections show it is likely that heavy rainfall and flooding will become more frequent. Continuing to provide new sewer capacity to cope with these growing risks is unaffordable.

Climate change projections also suggest that water shortages will become more frequent, especially in the south-east of England where demand is rising due to a growing population. This will increase pressure on our existing water supplies and we will need to find ways to be more efficient and creative in capturing and using the rainwater that falls on our urban areas.

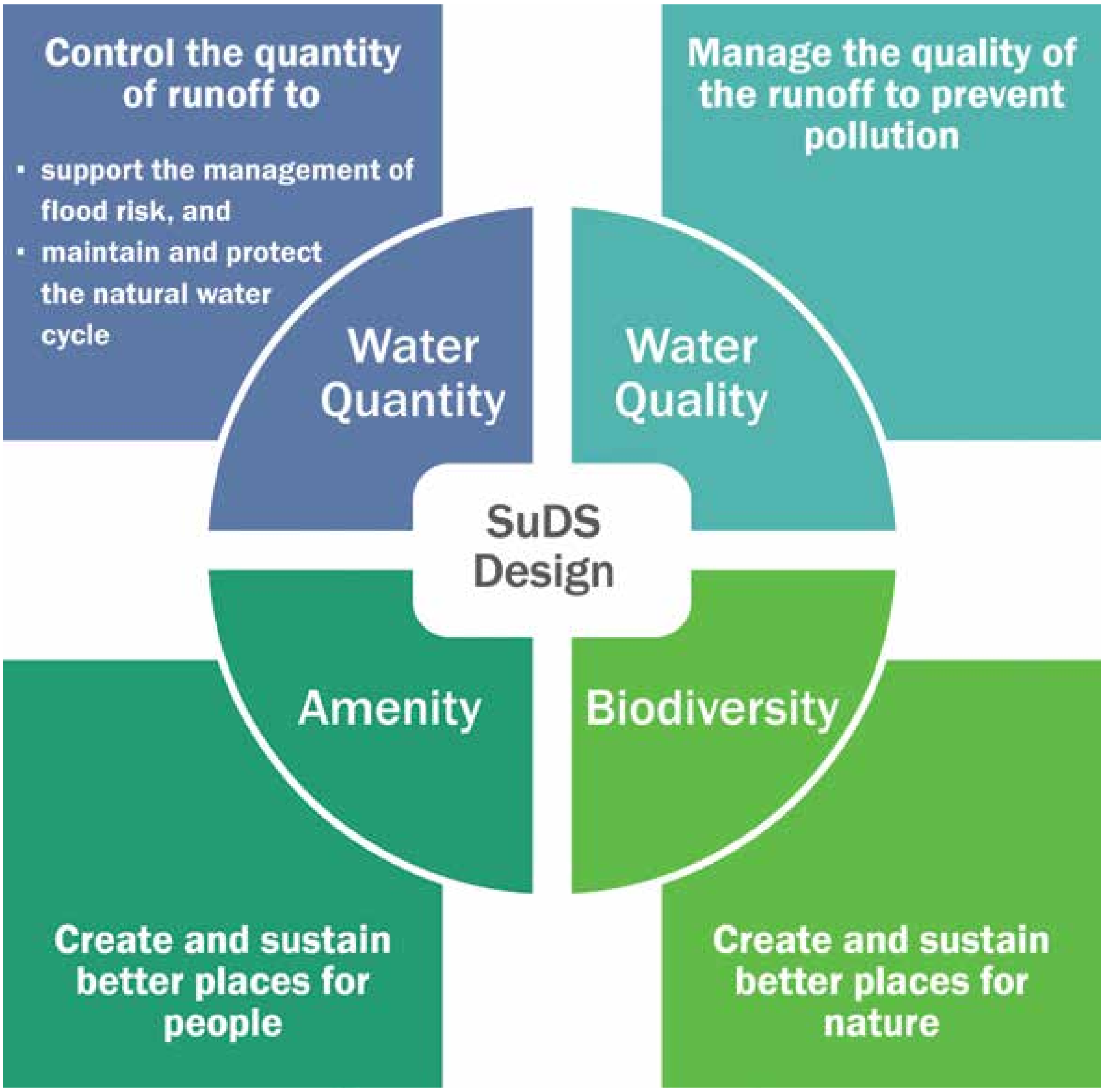
As well as contributing to more surface water runoff, increasing urbanisation has also reduced wildlife in urban areas. Where green spaces exist, these are often isolated from each other, which means that wildlife habitats become fragmented, preventing some species from being able to move between them. Eventually this leads to some species being lost from our green spaces, to the detriment of the local ecosystem and the human population.

What are SuDS?

Sustainable drainage systems (SuDS) are designed to maximise the opportunities and benefits we can secure from surface water management.

There are four main categories of benefits that can be achieved by SuDS: water quantity, water quality, amenity and biodiversity. These are referred to as the four pillars of SuDS design.

SuDS can take many forms, both above and below ground. Some types of SuDS include planting, others include proprietary/manufactured products. In general terms, SuDS that are designed to manage and use rainwater close to where it falls, on the surface and incorporating vegetation, tend to provide the greatest benefits. Most SuDS schemes use a combination of SuDS components to achieve the overall design objectives for the site.



courtesy Green Roof Consultancy

courtesy Dŵr Cymru Welsh Water

courtesy Greysmith Associates

courtesy Interpave

courtesy pallesh+azarfane

courtesy Essex County Council

Some examples of SuDS:

- Rainwater harvesting systems can collect rainwater from roofs and other paved surfaces for use on site.
- Green roofs, where a planted soil layer is constructed on a roof to create a living surface, can reduce surface runoff.
- Pervious pavements provide a hard surface that can be used for pedestrians or vehicles, while allowing rainwater to pass through to the soil or underground storage.
- Bioretention systems (including rain gardens) collect runoff, allowing it to pond temporarily on the surface before filtering through vegetation and underlying soils.
- Trees capture rainwater and provide evapotranspiration, biodiversity and shade.
- Swales, detention basins, ponds and wetlands slow the flow of water, store and treat runoff while draining it through the site and encouraging biodiversity.
- Soakaways and infiltration basins promote infiltration as an effective means of controlling runoff and supporting groundwater recharge.

What are the benefits of SuDS?

SuDS deliver high quality drainage while supporting urban areas to cope better with severe rainfall both now and in the future. SuDS also help counteract some of the impacts on our water cycle caused by increased urbanisation, such as reduced infiltration which in turn can result in diminished groundwater supplies.

SuDS can improve the quality of life in developments and urban spaces by making them more vibrant, visually attractive, sustainable and more resilient to change, by improving urban air quality, regulating building temperatures, reducing noise and delivering recreation and education opportunities. High quality SuDS designs that are integrated into the overall design of the development can attract tourism and investment, driving economic growth for the local area.

Where SuDS are designed to make efficient use of the space available, they can often cost less to implement than underground piped systems.

Where can you use SuDS?

SuDS can be used anywhere. SuDS can be used for new developments and redevelopments, and can be retrofitted into existing developments.

SuDS can be used in even the smallest spaces. Good SuDS design maximises the use of the available space by delivering efficient drainage together with other functions to help meet the objectives of the site. For example:

- pervious pavements can be used for parking
- rain gardens can be incorporated into traffic calming measures
- detention basins can also have recreational uses
- trees and green roofs can help to regulate building temperatures.

Most sites pose challenges of one sort or another, but the range of SuDS components and solutions available means that, with the timely engagement of the right expertise, effective SuDS schemes can be delivered for all developments. This includes:

- high density development sites
- steeply sloping sites

- flat sites
- sites with high groundwater levels
- sites within floodplains
- contaminated land sites
- sites with low infiltration capacity
- sites with unstable soils.

The three keys to successful SuDS implementation:

Consider how surface water runoff will be managed on your site from the start, and make it an integral part of the design process.

Put the right team together early in the process, so that urban planning, landscape architecture, architecture, drainage design and environmental aspects can be considered collectively.

Consult with relevant stakeholders early in the process, including the local planning authority, environmental regulator and those with responsibility for approving and maintaining the SuDS.

How do you design SuDS?

SuDS design should follow the guidance provided in the SuDS Manual, with due regard for any national or local regulatory requirements.

SuDS design should, as much as possible, be based around the following:

- using surface water runoff as a resource
- managing rainwater close to where it falls
- managing runoff on the surface
- allowing rainwater to soak into the ground
- promoting evapotranspiration
- slowing and storing runoff to mimic natural runoff characteristics
- reducing contamination of runoff through pollution prevention and controlling the runoff at source
- treating runoff to reduce the risk of urban contaminants causing environmental pollution.

Where to find further information

- A digital version of The SuDS Manual can be found at **www.ciria.org**
- A range of resources for those involved in delivering SuDS, including case studies, videos, presentations, fact sheets and links to research, can be found at: **www.susdrain.org**

courtesy Illman Young

courtesy Grant Associates

courtesy Robert Bray Associates

courtesy Illman Young

courtesy Studio Engleback

courtesy Peterborough City Council

Introduction to the SuDS Manual

SCOPE OF GUIDANCE

This guidance covers the planning, design, construction and maintenance of sustainable drainage systems (SuDS) to assist with their effective implementation within both new and existing developments. The guidance looks at how to maximise amenity and biodiversity benefits, and deliver the key objectives of managing flood risk and water quality. There is also supporting information covering topics such as materials, landscape design, community engagement and costs and benefits.

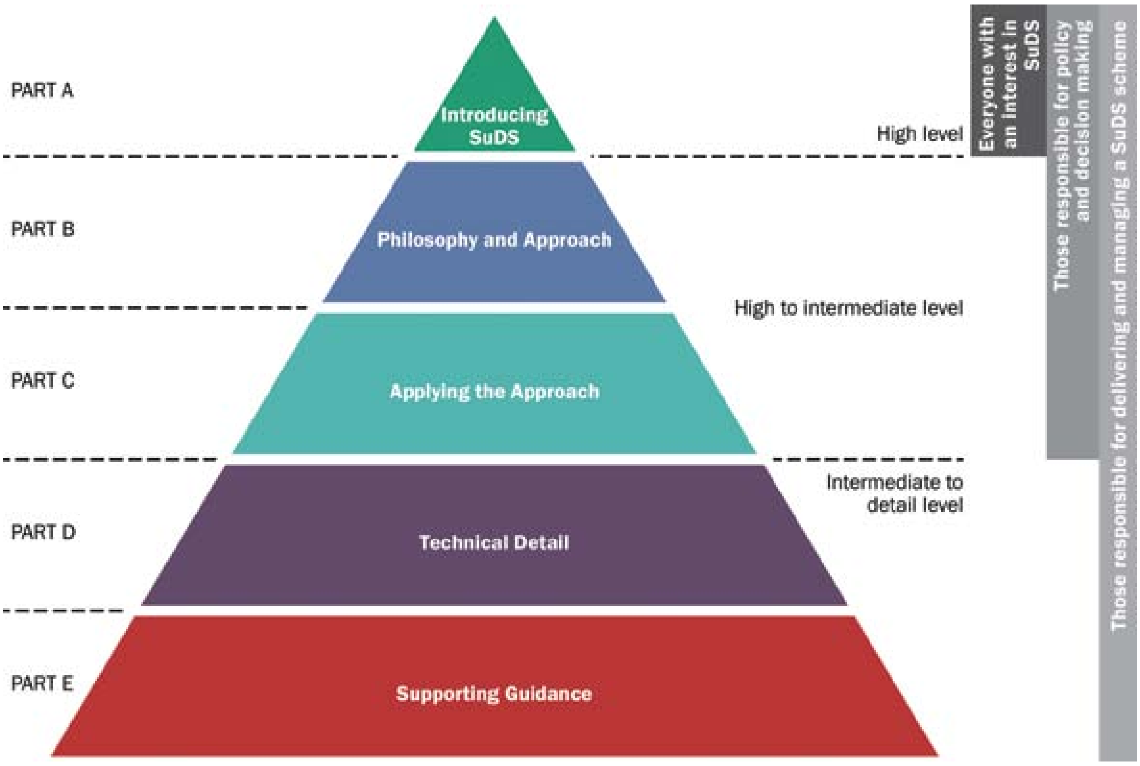
The guidance presented in this publication is a compendium of good practice, based on existing guidance and research in the UK and internationally and the practical experience of the authors, the project steering group and industry.

As experience of SuDS implementation and long-term maintenance continues to increase across the UK, lessons will continue to be learned. Also, continuing research on SuDS performance, both in the UK and internationally, will influence how design practice evolves. This guidance, however, provides a framework for designing SuDS with confidence and to maximise benefits.

The guidance is relevant for a wide range of professions and roles, including (in no particular order):

- drainage and flood risk management engineers
- architects and landscape architects
- planners and urban designers
- site owners and developers
- planning and drainage approval bodies
- environmental regulators
- ecologists
- highways and road authorities
- sewerage undertakers
- drainage and landscape contractors
- proprietary drainage and other product manufacturers.

This manual is divided into five sections and is colour coded based on these sections. It starts with a high-level overview and progresses into more detailed guidance in the later sections. The sections have different intended audiences, so the level of technical understanding expected of the reader increases through the manual.



Readers new to SuDS should focus initially on **Parts A to C**, before referring to **Parts D and E** for further information.

Readers familiar with SuDS are still advised to read all sections at least once, rather than just relying on **Parts D and E** to provide the guidance needed for detailed design. This is because the concepts covered in **Parts D and E** are introduced in **Parts B and C**, and it is important to understand the underpinning philosophy and approach.

The appendices provide detailed frameworks and checklists covering health and safety, design and construction. There is also a design example (**Appendix C**), which presents a hypothetical development site, to demonstrate the design process and the detailed design of individual SuDS components.

1. What are SuDS and why do we need them?	**Why SuDS?** **Chapter 1:** The philosophy of SuDS
2. What is good SuDS design?	**Chapter 2:** Introducing the SuDS design approach **Chapter 3:** Designing for water quantity **Chapter 4:** Designing for water quality **Chapter 5:** Designing for amenity **Chapter 6:** Designing for biodiversity
3. How do you plan and design a SuDS scheme?	**Chapter 7:** The SuDS design process **Chapter 8:** Designing for specific site conditions **Chapter 9:** Designing for roads **Chapter 10:** Designing for the urban environment
4. How do you design individual SuDS components?	**Chapter 11 to 23** (Technical details for individual SuDS components)
5. How do you calculate the hydraulic requirements for the site? (runoff rates, infiltration rates, storage volumes etc)	**Chapter 24:** Hydrology and hydraulics: Design methods and calculations **Chapter 25:** Infiltration: Design methods **Appendix C:** Design example
6. How do you limit pollution and manage water quality?	**Chapter 26:** Water quality management: Design methods **Chapter 27:** Pollution prevention strategies **Appendix C:** Design example
7. How do you ensure that the scheme is constructed and maintained effectively and functions as designed?	**Chapter 28:** Inlets, outlets and flow control systems **Chapter 29:** Landscape **Chapter 30:** Materials **Chapter 31:** Construction **Chapter 32:** Operation and maintenance **Chapter 33:** Waste management **Appendix B:** Checklists
8. How do you involve the community?	**Chapter 34:** Community engagement
9. How do you assess the costs and benefits of your scheme?	**Chapter 35:** Costs and benefits
10. How do you keep health and safety risks low?	**Chapter 36:** Health and safety

Relationship to other guidance

This publication replaces the original SuDS Manual (Woods Ballard *et al*, 2007).

This document does not include detailed information on planning requirements, SuDS approval and adoption processes or standards. These vary depending on region and should always be sourced and referred to early in the design process. National or (where appropriately adopted) local requirements may take precedence over the guidance set out in this manual, and this should be checked with the relevant planning, approving and maintenance bodies.

Also, this document does not cover in detail the specific technical challenges and planning issues associated with replacing piped drainage systems with SuDS at existing development sites (retrofitting). However, the design of retrofit SuDS should follow the same overall approach. Guidance specifically related to retrofitting can be found in Digman *et al* (2012).

SuDS is a key part of water sensitive urban design (WSUD), integrating the management of surface water runoff into the urban form (Abbott *et al*, 2013). However, WSUD has a broader consideration of the whole water cycle (ie including wastewater and water supply) and of the wider integration of development with watercourses and flood pathways, as part of an overall strategy within planning and urban design. In all other aspects, the aspirations and objectives are the same.

Document title	Description
Creating water sensitive places – scoping the potential for water sensitive urban design in the UK, CIRIA C724 (Abbott *et al*, 2013)	Provides details of the drivers, benefits and vision of WSUD in the UK.
Planning for SuDS – making it happen, CIRIA C687 (Dickie *et al*, 2010)	Provides information about the planning, master planning and development process and how they can be effectively used to deliver a more sustainable approach to drainage.
Retrofitting urban areas to effectively manage surface water, CIRIA C713 (Digman *et al*, 2012)	Provides guidance on how to retrofit surface water management measures into the urban environment, either as part of a strategic programme of work or by realising opportunities incrementally as they arise.
Designing for exceedance in urban drainage – good practice, CIRIA C635 (Balmforth *et al*, 2006)	Provides best practice advice for the design and management of urban sewerage and drainage systems to reduce the impacts that arise when flows occur that exceed their capacity.
Managing urban flooding from heavy rainfall – encouraging the uptake of designing for exceedance, CIRIA C738 (Digman *et al*, 2014)	Provides examples and ideas in a collection of case studies, plus lessons and success factors. Also provides a literature review of contemporary thinking in the UK and internationally regarding designing for exceedance.
Sustainable drainage systems: Maximising the potential for people and wildlife. A guide for local authorities and developers (Graham *et al*, 2012)	Describes how to maximise the biodiversity potential of SuDS and identifies a set of design criteria and the design features required to deliver these benefits; it also covers long-term management.
Water, people, places. A guide for master planning SuDS into developments (AECOM, 2013)	Outlines the process for integrating SuDS into the master planning of large and small developments.
BS 8582:2013 *Code of practice for surface water management for development sites*	Provides recommendations on the planning, design, construction and maintenance of surface water management systems for new developments and redevelopment sites.
Design manual for roads and bridges (DMRB) (Highways Agency, 2014)	Introduced in 1992 in England and Wales and then in Scotland and Northern Ireland, this provides a comprehensive manual system containing current standards, advice notes and other published documents related to trunk road works (including drainage).

There are many other guidance documents or design manuals for SuDS in the UK (including several CIRIA publications) that should be referred to for information on specific topics. These are referenced at the end of the chapters, but some of the key documents are listed below. The susdrain website provides a platform for sharing the latest good practice, and it highlights other relevant initiatives: **www.susdrain.org**

References

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Statutes

BS 8582:2013 *Code of practice for surface water management for development sites*

Everyone with an interest in SuDS

Those responsible for policy or decision making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS Manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

B

Audience:
Those responsible for policy or decision making
Those responsible for delivering and managing a SuDS scheme

Philosophy and approach

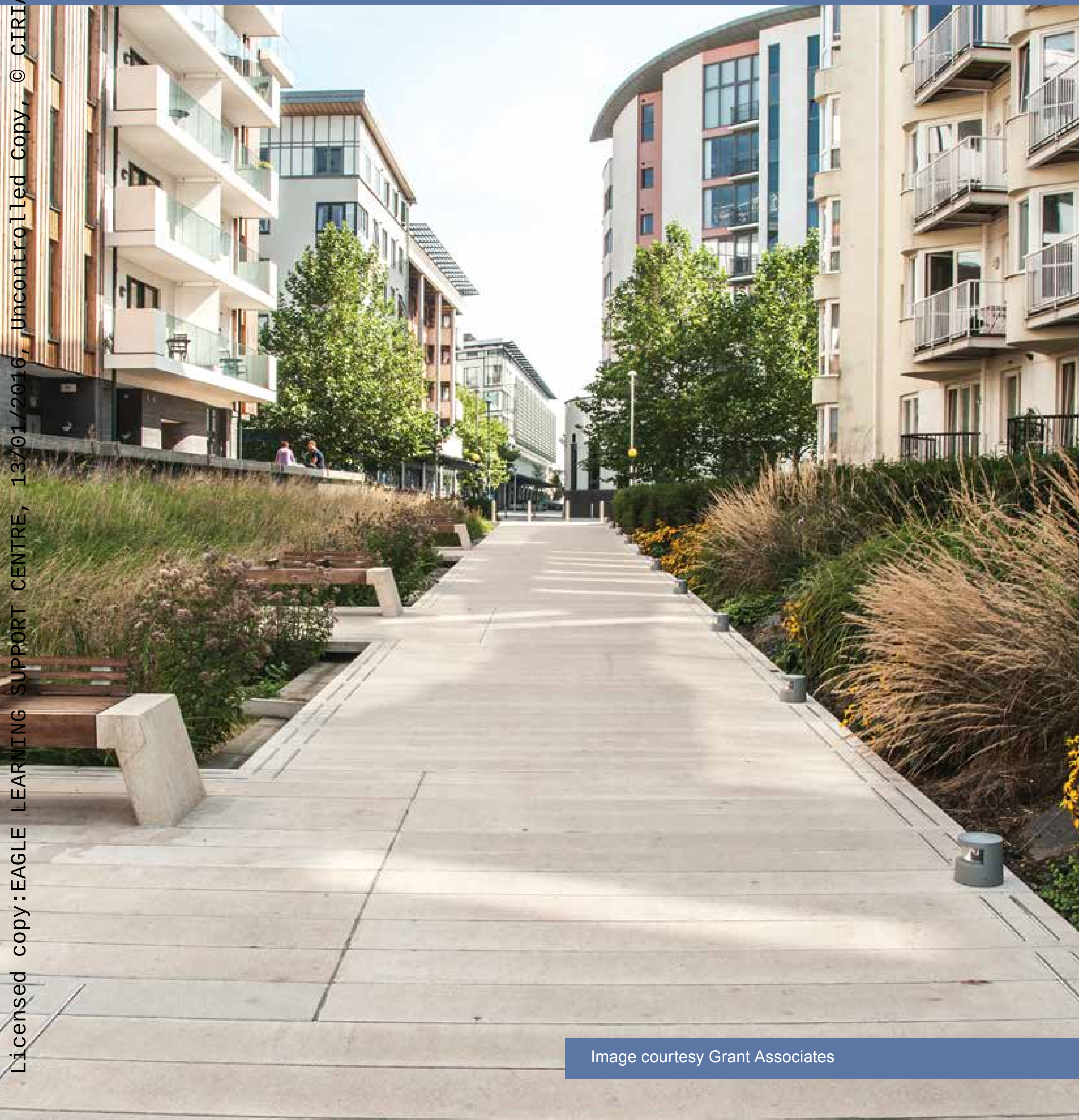

Image courtesy Grant Associates

Image courtesy Studio Engleback

1 THE PHILOSOPHY OF SUDS

Contents

Chapter

01

The philosophy of SuDS

This chapter discusses how SuDS can deliver multiple benefits, the importance of managing surface water runoff in a sustainable way and what makes a drainage system sustainable.

▶ *Chapters 2–10 provide further details of the concepts introduced here.*

1.1 DELIVERING MULTIPLE BENEFITS

Sustainable drainage systems (SuDS) can deliver multiple benefits

Surface water is a valuable resource and this should be reflected in the way it is managed and used in the built environment. It can add to and enhance biodiversity, beauty, tranquillity and the natural aesthetic of buildings, places and landscapes and it can help make them more resilient to the changing climate.

The philosophy of sustainable drainage systems is about maximising the benefits and minimising the negative impacts of surface water runoff from developed areas.

The SuDS approach involves slowing down and reducing the quantity of surface water runoff from a developed area to manage downstream flood risk, and reducing the risk of that runoff causing pollution. This is achieved by harvesting, infiltrating, slowing, storing, conveying and treating runoff on site and, where possible, on the surface rather than underground. Water then becomes a much more visible and tangible part of the built environment, which can be enjoyed by everyone.

By adopting this approach, SuDS have the opportunity to deliver and enhance the green space within developments and link to wider green networks, supporting the provision of habitats and places for wildlife to live and flourish. The benefits to the community of using SuDS are also numerous, including improvements in health, wellbeing and quality of life (liveability) for both individuals and communities, which in turn can increase the value of property and the prosperity of the local economy (**Box 1.1**).

To maximise these benefits, surface water management should be considered from the beginning of the development planning process and throughout – influencing site layout and design, and the use and characteristics of urban spaces (see **Case study 1.1**). So it is important that, where appropriate, an interdisciplinary team (including planners, landscape architects, architects and drainage engineers) should work together from the outset.

There are many different ways that SuDS can be applied to deliver effective surface water management that are both value for money and inspirational. Depending on the opportunities and constraints of the site, the type of development planned and the characteristics of the surrounding area, this can be through a combination of components – open water, vegetated and hard landscaped, above and below ground.

SuDS can be used in even the smallest spaces – the apparent lack of space should never be a reason for not using SuDS. Designing SuDS so that the space performs multiple functions is particularly important in dense urban areas where space is at a premium (**Box 1.2**).

This manual provides guidance for designers to enable them to make informed choices that suit their specific circumstances and maximise opportunities at reasonable cost.

BOX 1.1 **Benefits of SuDS**

- protecting people and property from increased flood risk resulting from the development
- protecting the quality of groundwater and surface waters from polluted runoff from the development
- protecting natural flow regimes (and thus the morphology and associated ecology) in rivers, lakes and streams
- supporting local natural habitats and associated ecosystems by encouraging greater biodiversity and linking habitats
- improving soil moisture and replenishing depleted groundwater levels
- providing society with a valuable supply of water
- creating attractive places where people want to live, work and play through the integration of water and green spaces with the built environment
- improving people's understanding of how runoff from their development is being managed and used, and the benefits of more sustainable approaches
- supporting the creation of developments that are more able to cope with changes in climate
- delivering cost-effective infrastructure that uses fewer natural resources and has a smaller whole-life carbon footprint than conventional drainage.

CASE STUDY 1.1 **The Circle, Uptown Normal, Illinois**

Figure 1.1 The Circle in Uptown Normal, Illinois, USA (courtesy Town of Normal)

The Circle is an award winning multi-functional public space located in a roundabout, providing green space that hosts many community events, including farmers markets, blues festivals and arts festivals (as shown in **Figure 1.1**). It collects runoff from surrounding streets to alleviate downstream flooding, infiltrates, stores and treats the runoff, re-circulates the water into a public fountain that provides cooling for the area and the space even abates surrounding vehicle noise.

BOX 1.2 The SuDS approach to managing surface water runoff

SuDS design should be based on the following, as much as possible, in order to maximise benefits:

- use surface water runoff as a resource
- manage rainwater close to where it falls (at source)
- manage runoff on the surface (above ground)
- allow rainwater to soak into the ground (infiltration)
- promote evapotranspiration
- slow and store runoff to mimic natural runoff rates and volumes
- reduce contamination of runoff through pollution prevention and by controlling the runoff at source
- treat runoff to reduce the risk of urban contaminants causing environmental pollution.

Depending on the characteristics of the site and local requirements, these may be used in combination and to varying degrees.

1.2 MANAGING SURFACE WATER RUNOFF

SuDS aim to mimic natural hydrological processes

The SuDS approach uses natural hydrology as the baseline against which system performance is evaluated.

Urbanisation alters the natural landscape and affects catchment hydrological processes. The natural water cycle maintains a balance of water circulation through evaporation, precipitation, infiltration/groundwater recharge and absorption and transpiration by plants. Urbanisation reduces the permeability of the land, replacing free draining ground with impermeable surfaces, such as roofs, roads, parking and other hard-scaping. Development often removes the natural vegetation that intercepts, slows and returns rainfall to the air, reduces the amount of water that can infiltrate into the ground, and this can significantly increase the rate at which water runs off the surface.

Figure 1.2 illustrates the impacts of urbanisation on a catchment by reducing its permeability and increasing surface water runoff.

The traditional method of draining surface water runoff from built-up areas, through underground pipe and tank storage systems, was intended to protect public health and prevent local flooding by taking the water away from source as quickly as possible. In many UK towns and cities, surface water runoff drains to a combined sewer where it mixes with sewage. In such systems, this can place a significant and unpredictable burden on wastewater treatment works, triggering some of the untreated sewage to spill into receiving watercourses via combined sewer overflows (CSOs). Flooding (contaminated with sewage) can also occur from surcharged manholes. In more recent developments, separate sewerage networks have generally been provided for the foul and the surface water systems. The foul water is piped to the wastewater treatment works, while the surface water is piped to the nearest watercourse. These separate surface water sewers reduce the risk of CSO spills, but still transfer the pollutants present in urban runoff (including potential misconnections) from the urban surface directly to receiving waters. Although attenuation tanks and flow controls may sometimes be used to control increased peak flow rates, changes in discharge frequencies and volumes are generally not addressed, and these can lead to physical impacts such as erosion and disturbance to habitats and ecosystems.

In the natural landscape, habitats such as peat bogs and heather moorland, broadleaved woodland, wildflower meadows and reed beds all serve as natural “sponges”, soaking up rainfall and filtering out contaminants. In developed areas, well-designed SuDS landscapes can offer some of the same opportunities by incorporating drainage elements such as green roofs, bioretention systems, wetlands and ponds that use the same natural processes (**Figure 1.3**).

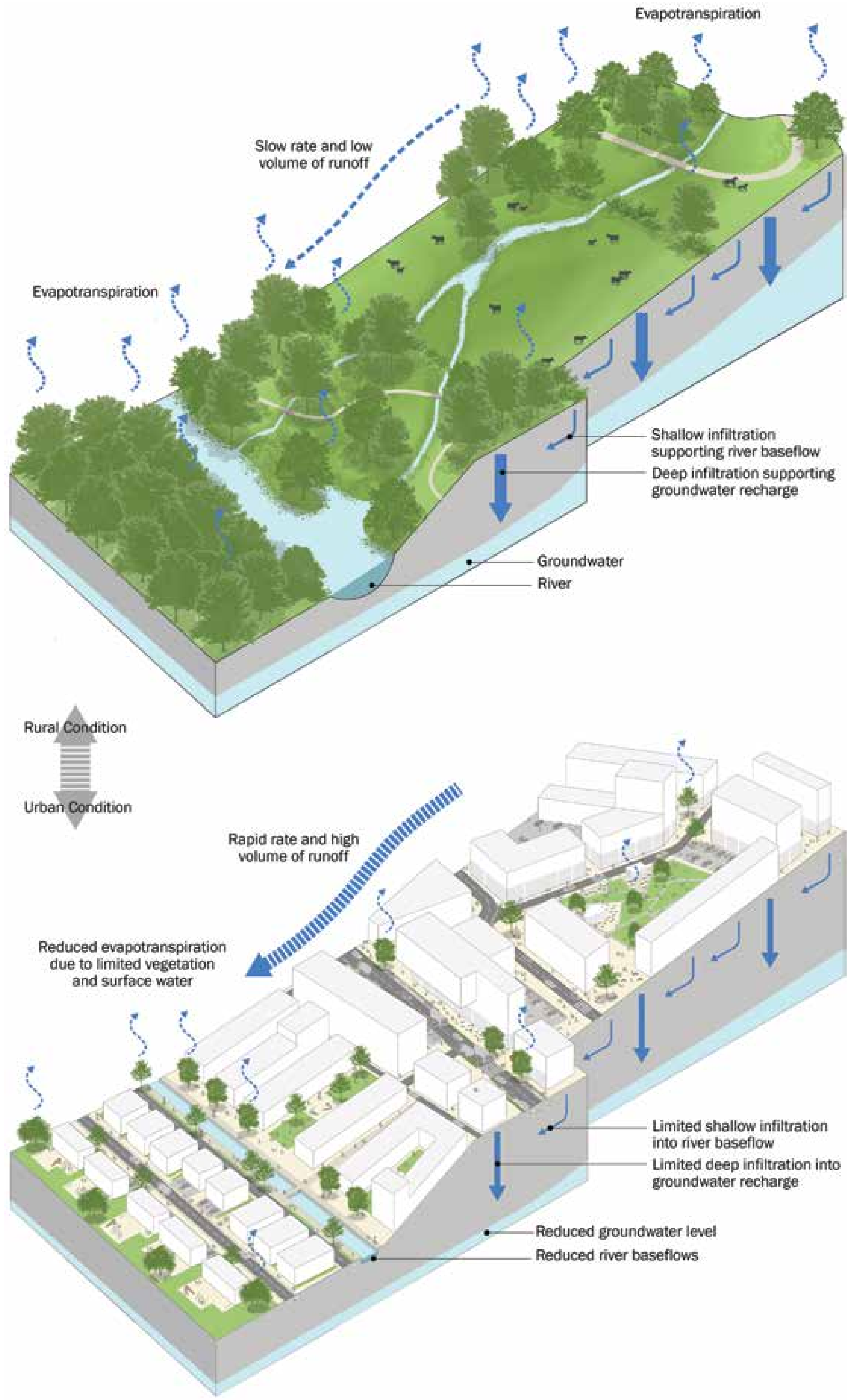

Figure 1.2 Impacts of urbanisation on a catchment

Bioretention system (courtesy Essex County Council)

Linear wetland

Grassland and wetland with native planting (courtesy Atelier Dreiseitl and GreenWorks)

Floating reed beds (courtesy Grant Associates)

Figure 1.3 SuDS using natural processes

SuDS are especially effective at restoring soil moisture and water balance, together with natural base flows. SuDS aim to restore or preserve the ecologically important elements of the pre-development runoff processes for a range of flow conditions from small to large rainfall events.

As surface water runoff washes over a developed catchment surface, it mobilises sediment, litter and a wide range of pollutants related to human activities (such as oils, grits, metals, fertilisers, pesticides, animal wastes, salts and pathogens). Without intervention, these eventually flow into rivers, groundwater and the sea, posing a risk to the environment and public health. As the pollution is widespread and comes from many types of sources and locations, it is known as “diffuse pollution” and although individual sources may not pose a threat, collectively they can potentially lead to significant impacts on groundwater or surface waters.

SuDS provide an opportunity to capture and treat runoff by intercepting, filtering and degrading pollutants, and by reducing the volume of potentially contaminated runoff.

Surface based SuDS components enable:

- the use of natural treatment processes associated with vegetation and the action of sunlight
- easy identification of sources of contamination, both acute (eg accidental spills) and chronic (long-term, ongoing pollution, including misconnections)
- cost-effective removal of trapped pollutant loads before they reach receiving waters
- cost-effective system remedial works.

1.3 DELIVERING RESILIENCE

SuDS can cope well with severe rainfall, climate change and increasing urbanisation

There is strong evidence that the earth's climate is changing because of human activity and that it will continue to change over the coming century, whether or not emissions of greenhouse gases are cut dramatically. Climate projections for the UK suggest that winters may become milder and wetter and summers may become warmer, particularly in the south-east. Some types of extreme events may become more frequent, such as heat waves, droughts and flooding, but due to the natural variability in the earth's weather and limitations with climate modelling, this is currently less certain.

Wetter winters and potentially more frequent and higher intensity rainfall events (in summer as well as winter) are expected to increase runoff from urban and agricultural land. This in turn would increase the risk of flooding, discharges from CSOs, diffuse pollution and soil erosion, with potentially negative impacts for the natural environment as well as the human population.

These impacts could also be exacerbated by increased runoff from urban intensification/urban creep: increasing density of development which increases the impermeability of developed areas, causing rates and volumes of runoff to rise, such as paving over gardens, extending buildings or adding roads.

SuDS offer a robust approach to managing rainfall events that exceed design conditions: rainfall more severe than allowed for in the system design. In surface based systems, water levels rise gradually and visibly during large rainfall events. With SuDS, excess runoff can be readily conveyed from within the drainage system into defined safe exceedance conveyance pathways and storage zones. This enables communities to understand and prepare for flooding more effectively than when served by subsurface systems, where flooding can occur suddenly, when the design capacity is exceeded.

SuDS also offer a more adaptable way of draining surfaces under the threat of both climate change and urban intensification. This is because surface based systems can be designed to offer more flexible capacity, and they tend to have greater potential for enhancement in the future at a reasonable cost compared to subsurface systems.

Water availability in the summer is expected to decrease, the consequences of which are likely to be exacerbated by higher temperatures. For example, lower flows in rivers in the summer months would lead to reduced dilution of pollutants in runoff when summer rainfall events do occur. There may also be more frequent algal blooms and eutrophication. At the same time, population growth and higher summer temperatures are likely to lead to greater demand for water. The competing pressures of maintaining public water supply without causing environmental damage need to be managed sustainably. SuDS can help by supplementing water supplies through rainwater harvesting and reducing pollutant discharges into receiving waters.

As well as these impacts on water systems, climate change is also likely to affect many aspects of urban living, especially human health. Elevated summer temperatures, for example, have been shown to cause additional deaths – especially in cities. SuDS in various forms can help to provide urban cooling (**Figure 1.4**). Hard surfaces tend to heat up in high temperatures, but this can be counteracted by providing SuDS with permanent water and/or vegetation. For example, green roofs can help to insulate buildings, green walls and vertical gardens can support natural ventilation (see **Case study 1.2**), trees provide shade, and water features cool the air.

Mature trees in planted swale (courtesy Illman Young)

Green wall (courtesy Green Roof Consultancy)

Green roof (courtesy Green Roof Consultancy)

Pond fed by water feature (courtesy Tim Crocker)

Figure 1.4 SuDS providing urban cooling

CASE STUDY 1.2 **Fair Street vertical rain garden, London**

Figure 1.5 Fair Street vertical rain garden (courtesy Dusty Gedge)

Rainwater from a downpipe runs into tanks located behind the living wall. Water from the rainwater storage tanks slowly seeps into the living wall, thereby irrigating the plants, attenuating the flows and reducing runoff through evapotranspiration.

1.4 MAKING DEVELOPMENTS MORE SUSTAINABLE

SuDS make developments more sustainable

Sustainable development aims to ensure a better quality of life, now and for generations to come. In the UK, this means meeting the following objectives (adapted from HM Government, 2005):

1. social progress that recognises the needs of everyone.
2. effective protection of the natural environment and processes.
3. the sustainable use of natural resources.
4. the maintenance of strong and stable levels of economic growth and employment.

Using SuDS for the sustainable management of surface water runoff can support:

- the management of flood risk through the control of both flow rates and volumes
- the preservation and support of habitats and biodiversity through the control of flows (and contaminants) to protect ecology and morphology
- the creation of sustainable habitats through the use of vegetated SuDS
- the prudent use of water resources through the implementation of rainwater harvesting systems
- the preservation of water resources through the protection of ground and surface water quality
- the sustainable use of natural resources through the minimisation of their use in SuDS design
- the reduction of embodied and operational carbon in drainage systems within manufacture and through the reduced use of pumping.

By taking advantage of natural systems and natural materials, most SuDS use fewer resources and less energy (leading to lower greenhouse gas emissions) than traditional drainage systems and, by using vegetation, can act as carbon sinks when in use.

Spatial planning and, in particular, local development planning policies and strategies are the most important instruments for promoting and delivering sustainable development in the UK. Taking a holistic and integrated approach to surface water management through the implementation of SuDS, improves water management and environmental protection at the strategic level (eg by contributing to green infrastructure), and contributes to local biodiversity and amenity objectives.

1.5 COMPLYING WITH LEGISLATION AND REGULATIONS

SuDS help deliver compliance with legislation and regulations

There are a great number of legal and other instruments that relate to the management of runoff and surface water. The European Union Water Framework Directive (European Commission, 2000) was transposed into UK national legislation in December 2003. This Directive takes account of all the different objectives for which the aquatic environment is protected (ecology, drinking water, health and particular habitats), and ensures that measures taken to achieve the objectives are co-ordinated properly.

The Water Framework Directive encourages a more sustainable approach to drainage by:

- establishing a holistic approach to managing the water environment, based on river basins, integrating water quantity with water quality considerations
- establishing quality objectives for all receiving waters, in order to achieve good status
- establishing a quality classification system for surface water that includes chemical, hydromorphological and ecological parameters

- establishing a quality classification system for groundwater status and a requirement for the quality of groundwater not to result in any significant damage to terrestrial ecosystems
- establishing controls in relation to pollution of receiving waters from point and diffuse sources
- preventing deterioration in the status of receiving waters
- promoting sustainable water use based on long-term protection of water resources
- achieving environmental objectives in a cost-effective way.

Measures to prevent or control diffuse sources of pollution is a basic requirement of the Directive (Article 11 (h)). This means that all discharges of urban runoff have to be managed such that their impact on the receiving environment is mitigated. This effectively precludes the use of the traditional approach to drainage unless special controls are used to slow down flows and treat the runoff. SuDS provide a means of addressing many of the requirements above.

SuDS also provide the means to simultaneously support the delivery of a broad range of national and European requirements and strategies including those relating to:

- flood risk management
- water resource management
- climate change resilience
- green infrastructure
- wetland creation
- biodiversity and wildlife, and
- carbon reduction.

In particular, there are national and local flood risk regulations and guidance that encourage the better management of surface water management, some explicitly promoting the use of SuDS (following on from the Pitt Review, 2008).

National planning policy across the four administrations of the UK require planning authorities to give priority to SuDS in planning applications.

1.6 THE SUDS DESIGN PHILOSOPHY

SuDS schemes use multiple components working together

SuDS should not be thought of as an individual component (such as a filter strip, swale or detention pond – see **Table 1.1**), but as an interconnected system designed to manage, treat and make best use of surface water, from where it falls as rain to the point at which it is discharged into the receiving environment beyond the boundaries of the site. The approach to SuDS design was summarised in **Box 1.2**.

A central design concept for SuDS is the **SuDS Management Train**. This describes the use of a sequence of components that collectively provide the necessary processes to control the frequency of runoff, the flow rates and the volumes of runoff, and to reduce concentrations of contaminants to acceptable levels. There are six specific functions provided by SuDS components. These are not independent, and one component may provide two or more functions. These are summarised in **Box 1.3**.

BOX 1.3 **Functions of SuDS components**

Rainwater harvesting systems – components that capture rainwater and facilitate its use within the building or local environment.

Pervious surfacing systems – structural surfaces that allow water to penetrate, thus reducing the proportion of runoff that is conveyed to the drainage system, eg green roofs, pervious paving. Many of these systems also include some subsurface storage and treatment.

Infiltration systems – components that facilitate the infiltration of water into the ground. These often include temporary storage zones to accommodate runoff volumes before slow release to the soil.

Conveyance systems – components that convey flows to downstream storage systems. Where possible, these systems also provide flow and volume control and treatment, eg swales.

Storage systems – components that control the flows and, where possible, volumes of runoff being discharged from the site, by storing water and releasing it slowly (attenuation). These systems may also provide further treatment of the runoff, eg ponds, wetlands and detention basins.

Treatment systems – components that remove or facilitate the degradation of contaminants present in the runoff.

There are many types of SuDS component, which means that sustainable drainage can be delivered anywhere. The designer can choose a number of different SuDS components and tailor the overall composition of a SuDS scheme to the local context (**Figure 1.6**). The designer can use the Management Train to create green corridors, link habitats together and add fun, education and amenity value. A summary of the types of SuDS component available to the designer is provided in **Table 1.1**. Detailed descriptions of these components are provided in **Chapters 11–23**.

Wherever possible, runoff should be managed at source (ie close to where the rain falls) with residual flows then conveyed downstream to further storage or treatment components, where required. The passage of water between individual components of the Management Train should be, wherever possible, through the use of above-ground conveyance systems (eg swales and rills) although pipework and subsurface proprietary products may prove more efficient for specific schemes, especially where space is limited such as in a redevelopment. Pre-treatment (the removal of litter and sediment) and maintenance are vital to ensure the long-term and sustained effectiveness of all SuDS components. Overland flow routes will also be required to convey and control floodwater safely during extreme events (**Section 1.3**).

TABLE 1.1 Types of SuDS components

Component type	Description	Further information
Rainwater harvesting systems	Rainwater is collected from the roof of a building or from other paved surfaces in an over-ground or underground tank for use on site. Depending on its intended use, the system may include treatment elements. The system should include specific storage provision if it is to be used to manage runoff to a design standard.	Chapter 11
Green roofs	A planted soil layer is constructed on the roof of a building to create a living surface. Water is stored in the soil layer and absorbed by vegetation. Blue roofs store water at roof level, without the use of vegetation.	Chapter 12
Infiltration systems	These systems collect and store runoff allowing it to infiltrate into the ground. Overlying vegetation and underlying unsaturated soils can offer protection to groundwater from pollution risks.	Chapter 13
Proprietary treatment systems	These subsurface and surface structures are designed to provide treatment of water through the removal of contaminants.	Chapter 14
Filter strips	Runoff from an impermeable area is allowed to flow across a grassed or otherwise densely planted area to promote sedimentation and filtration.	Chapter 15
Filter drains	Runoff is temporarily stored below the surface in a shallow trench filled with stone/gravel, providing attenuation, conveyance and treatment (via filtration).	Chapter 16
Swales	A vegetated channel is used to convey and treat runoff (via filtration). These can be “wet”, where water is designed to remain permanently at the base of the swale, or “dry” where water is only present in the channel after rainfall events. It can be lined, or unlined to allow infiltration.	Chapter 17
Bioretention systems	A shallow landscaped depression allows runoff to pond temporarily on the surface, before filtering through vegetation and underlying soils prior to collection or infiltration. In its simplest form it is often referred to as a rain garden. Engineered soils (gravel and sand layers) and enhanced vegetation can be used to improve treatment performance.	Chapter 18
Trees	Trees can be planted within a range of infiltration SuDS components to improve their performance, as root growth and decomposition increase soil infiltration capacity. Alternatively they can be used as standalone features within soil-filled tree pits, tree planters or structural soils, collecting and storing runoff and providing treatment (via filtration and phytoremediation).	Chapter 19
Pervious pavements	Runoff is allowed to soak through structural paving. This can be paving blocks with gaps between solid blocks, or porous paving where water filters through the block itself. Water can be stored in the sub-base and potentially allowed to infiltrate into the ground.	Chapter 20
Attenuation storage tanks	Large, below-ground voided spaces can be used to temporarily store runoff before infiltration, controlled release or use. The storage structure is often constructed using geocellular or other modular storage systems, concrete tanks or oversized pipes.	Chapter 21
Detention basins	During a rainfall event, runoff drains to a landscaped depression with an outlet that restricts flows, so that the basin fills and provides attenuation. Generally, basins are dry, except during and immediately following the rainfall event. If vegetated, runoff will be treated as it is conveyed and filtered across the base of the basin.	Chapter 22
Ponds and wetlands	Features with a permanent pool of water can be used to provide both attenuation and treatment of runoff, where outflows are controlled and water levels are allowed to increase following rainfall. They can support emergent and submerged vegetation along their shoreline and in shallow, marshy zones, which enhances treatment processes and biodiversity.	Chapter 23

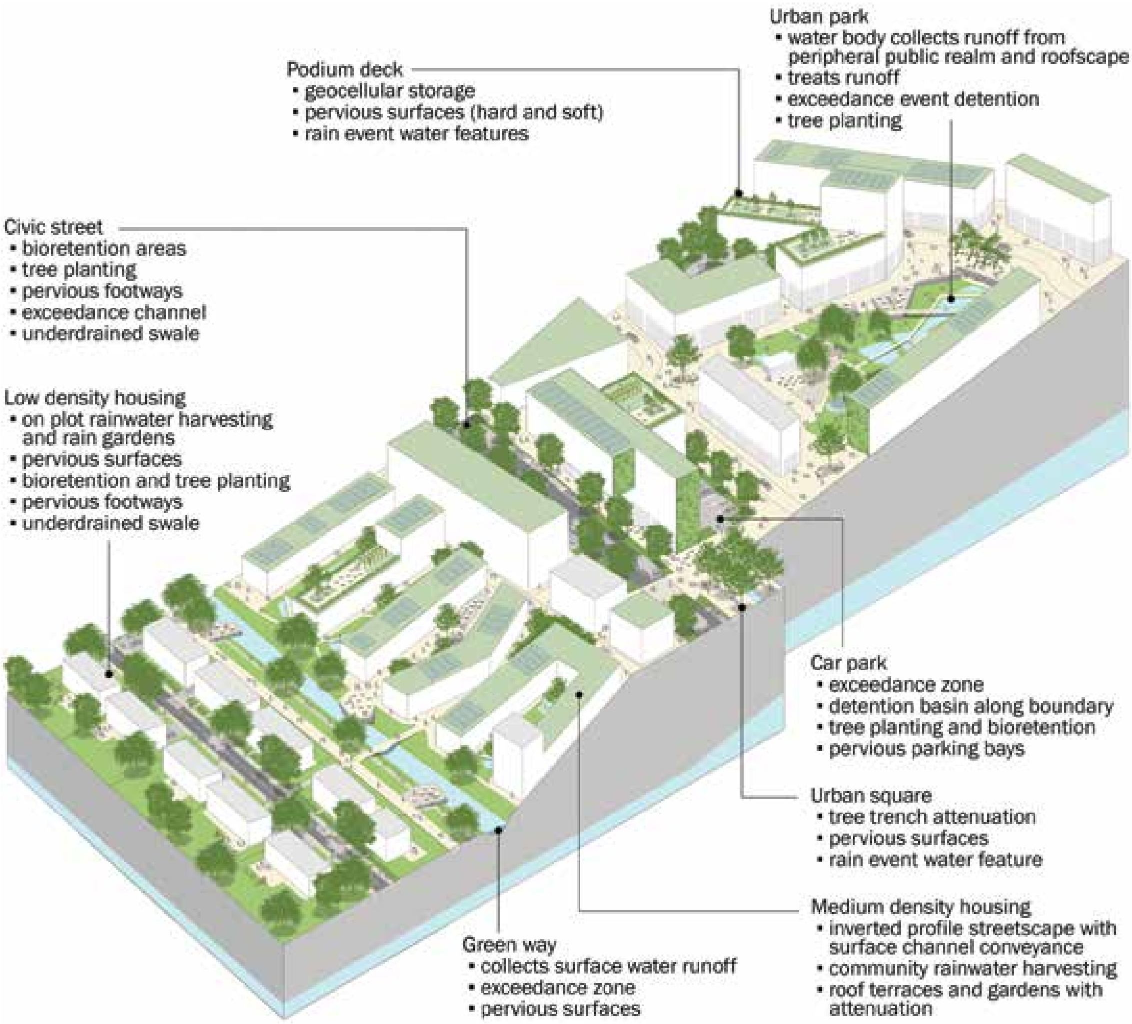

Figure 1.6 Examples of commonly used SuDS for different development types

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2 INTRODUCING THE SUDS DESIGN APPROACH

Contents

Chapter 02

Introducing the SuDS design approach

This chapter introduces the overarching principle of SuDS design; the four broad objectives related to water quantity, water quality, amenity and biodiversity; and the design criteria that should be followed to deliver these objectives.

▸ *This chapter should be read alongside Chapters 3–6, which describe the design criteria in more detail, accompanied by good practice design standards.*

2.1 THE PRINCIPLE AND OBJECTIVES OF SUDS DESIGN

The overarching principle of SuDS design is that **surface water runoff should be managed for maximum benefit.**

The types of benefits that can be achieved by SuDS will be dependent on the site, but fit broadly into four categories: water quantity, water quality, amenity and biodiversity. These are also referred to as the four pillars of SuDS design (**Figure 2.1**). Each of these pillars has a design objective, as presented in **Figure 2.1**.

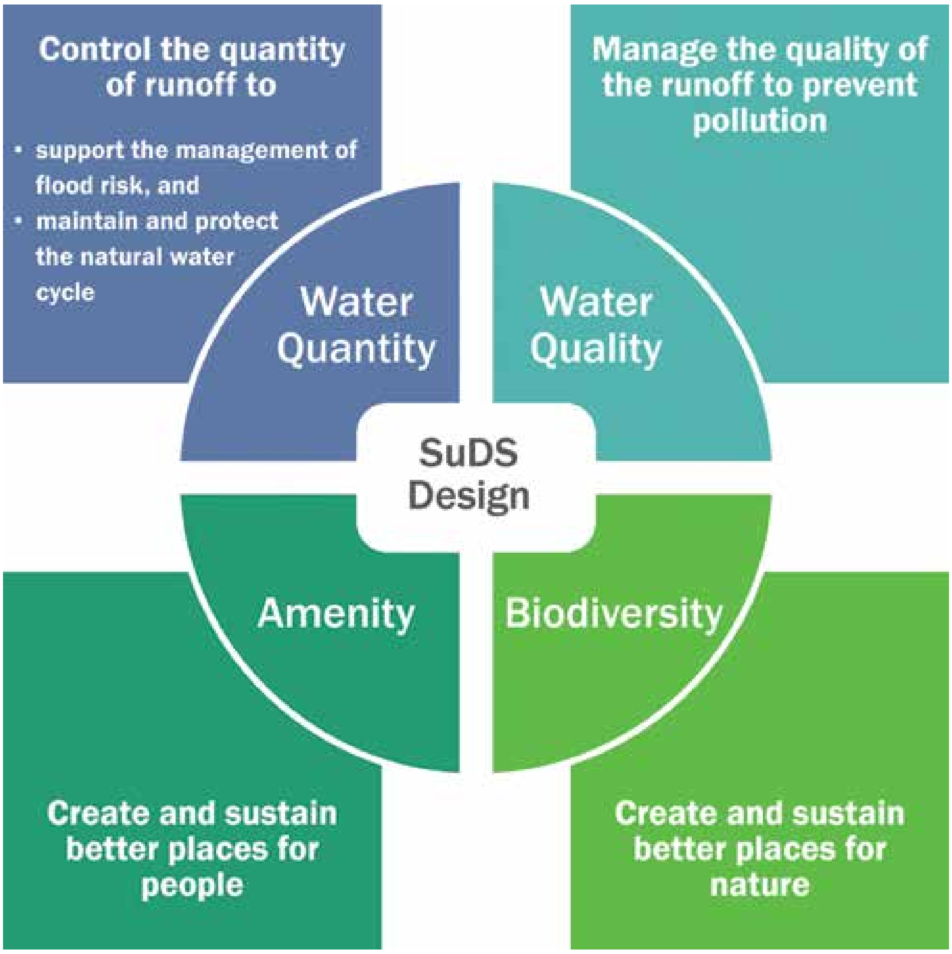

Figure 2.1 The four pillars of SuDS design

2.2 SUDS DESIGN CRITERIA

In order to deliver the design objectives of Figure 2.1, there are different aspects of SuDS design that need to be taken into consideration. These are referred to here as design criteria, and are summarised in Table 2.1. Chapters 3–6 discuss the four criteria.

TABLE 2.1 Design criteria for SuDS

	Design criteria	Further information
Water quantity	1 Use surface water runoff as a resource 2 Support the management of flood risk in the receiving catchment 3 Protect morphology and ecology in receiving surface waters 4 Preserve and protect natural hydrological systems on the site 5 Drain the site effectively 6 Manage on-site flood risk 7 Design system flexibility/adaptability to cope with future change	Chapter 3
Water quality	1 Support the management of water quality in the receiving surface waters and groundwaters 2 Design system resilience to cope with future change	Chapter 4
Amenity	1 Maximise multi-functionality 2 Enhance visual character 3 Deliver safe surface water management systems 4 Support development resilience/adaptability to future change 5 Maximise legibility 6 Support community environmental learning	Chapter 5
Biodiversity	1 Support and protect natural local habitats and species 2 Contribute to the delivery of local biodiversity objectives 3 Contribute to habitat connectivity 4 Create diverse, self-sustaining and resilient ecosystems	Chapter 6

Note
Definitions for resilience, flexibility and adaptability can be found in the glossary (Appendix A).

These design criteria can and should be given full consideration for all types of development. The extent and way in which each criterion can be delivered will depend on site characteristics, development context and local objectives. The water quantity and water quality criteria are likely to be the main drivers in determining the design philosophy for a site, and these are supported by standards (expected levels of service) for the surface water management system. Maximising delivery of amenity and biodiversity criteria will often deliver on a range of other required planning outcomes/objectives for the site.

The criteria are not independent of each other. For example, a bioretention system draining an area of urban road may deliver on all of the criteria simultaneously. There are also a number of criteria that are cross-cutting. For example, using runoff as a resource will support both water quantity and amenity design objectives.

In order to maximise opportunities and the associated benefits, the criteria should be considered at an early stage and fully integrated into the surface water management and urban design process (Chapter 7). In so doing, it is then possible to ensure that the scheme is truly multi-functional and delivers the highest return for the developer and for the community who will live there. As well as the SuDS design criteria, there are more generic criteria of good design that are required to ensure a safe, functional and cost-effective SuDS scheme. These generally fall into the four categories listed in Table 2.2. Further discussion of these aspects of design can be found in the chapters indicated, although reference to these is also made throughout the manual.

TABLE 2.2 Generic criteria of a good design

	The design of a SuDS scheme should ensure that...	Further information
Constructability	It can be easily and safely constructed.	Chapter 31
Maintainability	It can be easily and safely maintained.	Chapter 32
Cost-effectiveness	The site is drained to meet the required standards of service, while maximising the potential benefits from delivery of the criteria, at an affordable cost both initially to the developer and for those responsible for the long-term operation and maintenance of the system.	Chapter 35
Health and safety	It is safe for those living near or visiting the system, and for those involved in its operation and maintenance.	Chapter 36

2.3 THE ROLE OF THE DESIGNER

The design objectives and criteria presented in **Sections 2.1 to 2.3** provide a framework for the designer to work within, but it remains the responsibility of the designer to choose how to apply these to a specific scheme. Central to this is the need to engage stakeholders early, including those with responsibility for approving, adopting or maintaining the SuDS scheme, the environmental regulator, sewerage undertaker and roads authorities. Opportunities for SuDS will be maximised through collaborative working between engineers, landscape architects, planners, architects and the local community (**Chapter 34**).

The design process is about delivering the design criteria in a way that balances and optimises the benefits versus the costs of alternative options – working with the opportunities and constraints of the site, and with stakeholder and regulatory requirements.

2.4 ASSESSING AND APPROVING SUDS SCHEMES

Although design of high-quality SuDS is as much an art as a science, it is important that a SuDS design can be assessed, to determine whether it delivers the design criteria adequately.

Indicators – these are the means of measuring the extent to which the design criteria are being achieved. Example indicators are presented in **Chapters 3–6**. These should be selected and/or amended to suit the local application.

Standards – these are the minimum performance targets or levels of service that SuDS designs should meet. The standards set out in this manual are "standards of good practice". Many of these standards are also set out in other best practice documents (that have been approved by the environmental regulator), and/or statutory national standards. Local standards (alongside local guidance) may be set out by Local Authorities and other approving or adopting bodies, which could take precedence.

Checklists – provided in **Appendix B**, cover the following areas:

- health and safety risk assessment
- design process: staged submission requirements
- SuDS component design
- construction standards, method statements and inspections
- adoption and maintenance evaluation and planning.

3 DESIGNING FOR WATER QUANTITY

Contents

Chapter 03

Designing for water quantity

This chapter explains the objective of designing for water quantity and the design criteria that should be followed to deliver this objective. Good practice design standards are also presented.

▶ *This chapter should be read alongside Chapters 4–6, to understand how the different SuDS design criteria relate to each other, and Chapter 7 to understand when and how to apply these criteria.*

3.1 WATER QUANTITY DESIGN OBJECTIVE

Control the quantity of runoff to support the management of flood risk and maintain and protect the natural water cycle

In order to ensure that the surface water runoff from a developed site does not have a detrimental impact on people, property and the environment, it is important to control:

- how fast the runoff is discharged from the site (ie the peak runoff rate) and
- how much runoff is discharged from the site (ie the runoff volume).

SuDS that are designed to manage water quantity in this way reduce the likelihood of flooding caused by the development. They can help protect natural water cycles by promoting the recharge of soil moisture levels (and subsequent evapotranspiration processes), by maintaining stream and river baseflows, and by replenishing groundwater. They can also help reduce the risk of erosion of the banks and riverbed, caused as a result of the receiving watercourse experiencing more frequent bankfull or near bankfull conditions. Such erosion increases sediment loads and can degrade the ecological health of the watercourse.

SuDS are most effective at reducing flood risk for relatively high intensity, short and medium duration events. So SuDS are particularly important in mitigating potential increases in surface water flooding, sewer flooding and flooding from small and medium sized watercourses resulting from development. SuDS tend to have less impact on flood risk associated with larger rivers that are more sensitive to long duration events (such as the Thames or the Somerset Levels). However, this does not mean that SuDS are not required. Local hydraulic constraints and flow characteristics may mean that flow and volume control are still necessary for managing local flood risk and providing groundwater recharge, where appropriate. Reducing pollution, together with delivering amenity and biodiversity benefits for the site are also still very important.

SuDS for a single site could potentially be demonstrated to have limited impact, but it is the cumulative impact of all development in the catchment (combined with the potential effects of climate change) that should be taken into consideration.

3.1.1 Why should peak runoff rates be controlled?

Peak rates of surface water runoff discharged from a developed (ie relatively impermeable) site, if left uncontrolled, are normally significantly greater than from the site in its greenfield state. This is because the runoff drains off the surfaces of the developed site much quicker than the greenfield site and there is much more runoff, as less water is able to penetrate the ground or be intercepted in other ways. On sites overlying sandy, well-drained soils, peak rates could be at least an order of magnitude higher. This can have significant consequences for the receiving watercourse by increasing flow velocities and the likelihood of flooding and bank erosion. Where sites discharge to existing piped drainage systems, the risks tend to be even greater, as pipes have constrained capacities and are more sensitive to changes in flow rate.

Figure 3.1 shows the pre-development or greenfield discharge rate (green line) compared to the uncontrolled post-development discharge rate (blue line). The post-development peak is much higher and arrives much earlier than the pre-development peak.

So the purpose of controlling peak runoff rates is to limit the rate of runoff after development to the rate that would have occurred before development. This can be achieved by the process of attenuation: slowing and storing runoff on site and then discharging it at a specified maximum rate to the receiving watercourse (**Figure 3.2**). This is discussed further in **Section 3.1.2**.

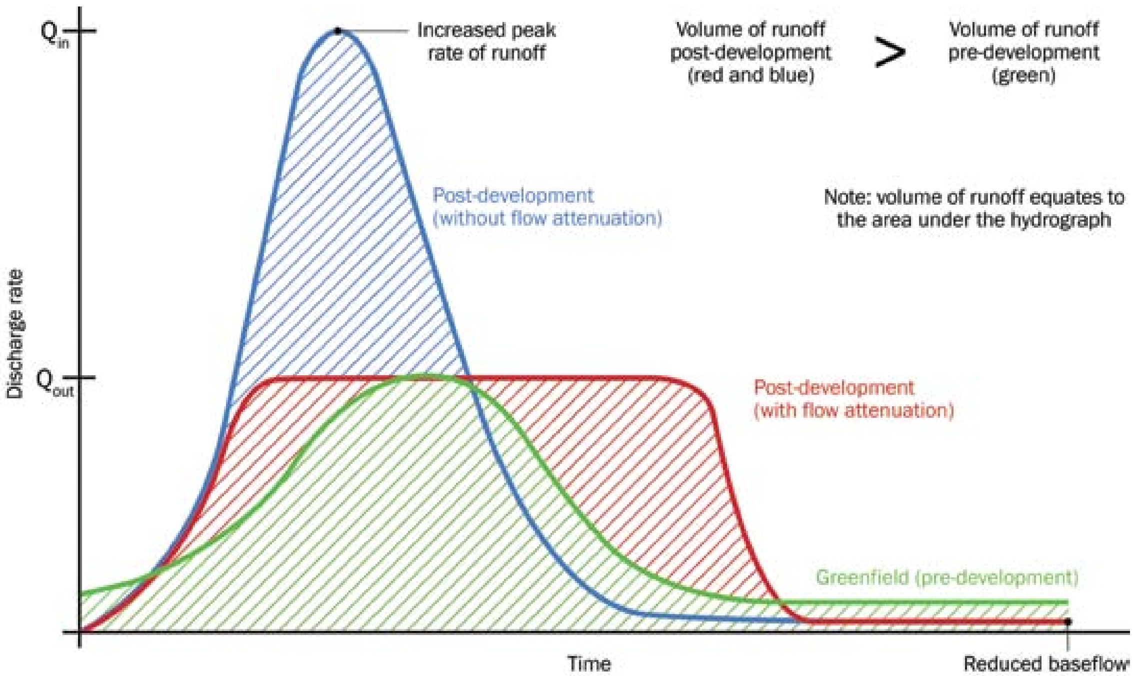

Figure 3.1 Example of a runoff hydrograph

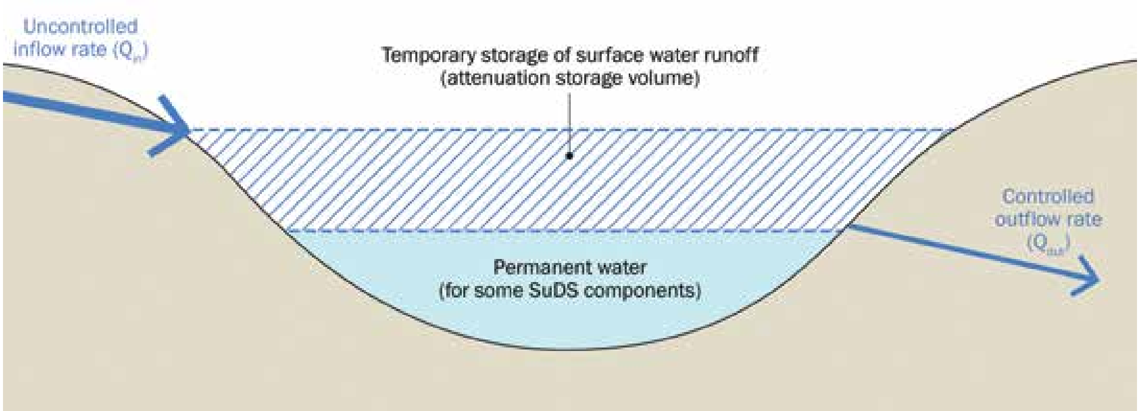

Figure 3.2 Controlling runoff rates using attenuation storage

3.1.2 Why should runoff volumes be controlled?

Attenuation (as discussed in **Section 3.1.1**) controls the peak runoff rate by extending the hydrograph (**Figure 3.1**). So while the peak rate of runoff may not increase, the duration over which this peak rate occurs will be significantly longer than before development as a result of the additional runoff volume. This can also increase the likelihood of flooding in the receiving watercourse. Where sites discharge to sewer systems, changes in volumes are particularly important, due to the risk of sewer flooding and CSO spills.

Figure 3.1 shows the post-development discharge rate with attenuation in red. The volume of runoff is the area under the graph. This extended period of peak flows in the receiving watercourse can be damaging for both morphology and ecology, caused by greater erosion and movement of sediment. Therefore, controlling peak runoff rates from large storm events is extremely important, but it is not sufficient on its own to reduce the impact of the development on the downstream catchment.

Also, attenuation can only control relatively large rainfall events, and does nothing to address the problems associated with a development site generating runoff from all of the smaller rainfall events. With natural soil conditions, the runoff from the majority of such events (ie with a total depth of, say, 5 mm or less) would have been lost through infiltration and/or evapotranspiration. Runoff from these frequent small rainfall events will usually just “pass through” attenuation systems with limited or no control.

At a catchment scale, the potential limitations of using attenuation alone are also evident (**Figure 3.3**). Although the runoff from each sub-catchment has been attenuated to limit flows to pre-development conditions, the peak flow downstream will continue to rise because of the greater total volumes being discharged from each sub-catchment. This means that the likelihood of flooding downstream still increases.

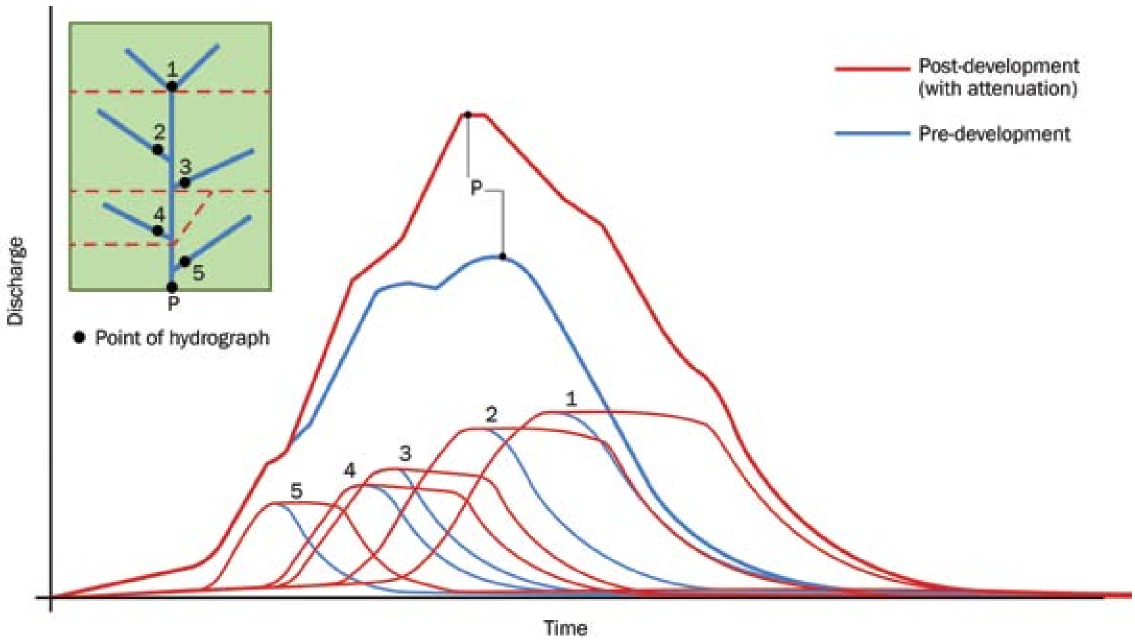

Figure 3.3 Example of the combined effect of multiple attenuation systems

3.2 WATER QUANTITY DESIGN CRITERIA

3.2.1 Summary

The design criteria presented here should be applied to manage the quantity of water to deliver the design objective described in **Section 3.1**. The opportunities for a designer to apply these design criteria in full will depend on site characteristics, development context and local planning objectives. To maximise these opportunities, the design criteria should be considered at an early stage of the design process and fully integrated into that process.

Managing water quantity can also contribute to the design objectives for water quality, amenity and biodiversity. So these design criteria should be considered alongside design criteria for water quality, amenity and biodiversity (**Chapter 2, Table 2.1 and Chapters 4–6**).

Indicators can be used to evaluate the extent to which design criteria are being delivered by the SuDS design. Water quantity design criteria and example indicators are presented in **Table 3.1**.

TABLE 3.1 Water quantity design criteria and example indicators

Water quantity design criterion	Example indicator
1 Use surface water runoff as a resource	A proportion of runoff from rainfall events is harvested for use or infiltrated to support river baseflows and/or recharge groundwater.
2 Support the effective management of flood risk in the receiving catchment	Discharges to surface waters are prioritised over discharges to sewers. The rates and volumes of runoff for high return period events are controlled in accordance with the water quantity standards (**Section 3.3**).
3 Protect morphology and ecology in receiving surface waters	The rates and volumes of runoff for low return period events are controlled in accordance with the water quantity standards (**Section 3.3**).
4 Preserve and protect natural hydrological systems on the site	The natural hydrological drainage systems on the site are preserved or enhanced as part of the landscape and/or surface water management system.
5 Drain the site effectively	Runoff from all rainfall events infiltrates or drains through the SuDS within a suitable time, so that the performance of the system for managing runoff from subsequent rainfall events is not reduced.
6 Manage on-site flood risk	Runoff from rainfall events that exceeds the SuDS capacity is managed in identified exceedance routes and storage areas.
7 Design in system flexibility/ adaptability to cope with future change	The SuDS design includes climate change and urban creep allowances, or is designed with the flexibility (and funding) to be suitably adapted during its design life.

These design criteria are discussed in more detail in the following subsections. Where minimum performance targets or specific levels of service should be achieved by a SuDS design, these are detailed in **Section 3.3**, and guidance is provided as to how these can be met. These generally mirror legislative or regulatory standards where they exist. However, local standards, as set out in supplementary planning documents (SPDs), may take precedence.

3.2.2 Water quantity criterion 1: Use surface water runoff as a resource

Using surface water runoff as a resource contributes to the water sensitive urban design (WSUD) philosophy of integrating water cycle management with the built environment (Morgan *et al*, 2013).

It is advantageous to design drainage systems that capture and use surface water because this (a) helps to reduce runoff volumes from the site and (b) allows this valuable resource (water) to be put to good use. This demonstrates how some amenity benefits are intrinsic in SuDS design.

Rainfall is likely to become an even more valuable resource in the future, as water becomes more scarce, due to climate change and rising population.

Direct harvesting at or near source for garden watering has been common practice for many years. In parts of the UK, especially the south-east of England, water resources are increasingly under stress due to rising demand for water and climate change. In such areas, harvested rainwater is increasingly being used for other purposes, but it may require treatment where there is a risk of human contact or consumption. (The level of treatment should be proportionate to the level of risk.) Harvested rainwater can be used for irrigating landscapes, and roof water can often be used directly for private or communal gardens and allotments, for car washing or for toilet flushing. Rainwater storage systems can be located in roof voids, beneath gardens, garages, driveways or areas of communal open space, or be part of boundary walls (**Chapter 11**).

Using surface water runoff as a resource can provide amenity benefits as well as water quantity benefits. For example, SuDS can be designed to support areas for water play and urban horticulture, providing recreational, educational and health and well-being benefits. These are discussed in **Chapter 5** under: **Amenity criterion 1: Maximise multi-functionality**.

Using SuDS to promote infiltration is another way of protecting water resources, as this can potentially contribute both to the recharge of aquifers and to interflows through upper soil horizons that support baseflows in local rivers and streams (that may subsequently be abstracted for supply purposes).

3.2.3 Water quantity criteria 2 and 3: Support the management of flood risk in the receiving catchment, and protect morphology and ecology in receiving surface waters

To ensure that the site does not have a detrimental impact on the downstream catchment (increasing flood risk or causing morphological or ecological damage) and protects the natural water cycle, designers should do each of the following (which are discussed below):

1. Prioritise where surface water runoff is discharged.
2. Control the volume of runoff discharged from the site.
3. Control the peak runoff rates from the site.

Some receiving surface waters, such as estuaries, some large lakes and the sea, are normally not sensitive to the runoff from developed sites. In these cases, the control of peak runoff rates and runoff volumes is not necessary. However, even for these scenarios, SuDS are still important, particularly for the water quality benefits, but also for the amenity and biodiversity value they bring.

1 Prioritise where surface water runoff is discharged

The destination for surface water runoff that is not collected for use should be prioritised in the following order:

a infiltration
b discharge to surface waters
c discharge to a surface water sewer, highway drain or another drainage system
d discharge to a combined sewer.

Discharge to a foul sewer should not be considered as a possible option.

As much of the runoff as possible (subject to technical or cost constraints) should be discharged to each destination before a lower priority destination is considered.

Depending on the site characteristics, drainage from different parts of the site could have different drainage destinations.

Depending on the quantity of runoff and the potential for a particular destination to manage that runoff, small events might be discharged to a higher level destination, while larger events may need to utilise a lower priority destination.

Where runoff is to be discharged to a sewerage undertaker's surface water sewer or combined sewer, the sewerage undertaker should be consulted as to whether any additional criteria or limiting discharge rates are required.

Where runoff is to be discharged to a watercourse, the relevant local flood authority should be consulted.

2 Control the volume of runoff discharged from the site

The volume of runoff discharged from the site should be controlled for both frequent and extreme events by maximising opportunities to:

a use surface water runoff as a resource

b intercept and reduce runoff through evapotranspiration (eg using green roofs, trees or vegetated storage systems)

c intercept and reduce runoff through infiltration (eg using soakaways, bioretention systems, permeable pavements or infiltration basins).

See **Section 3.3.1** water quantity standard 1.

3 Control peak runoff rates from the site

Peak runoff rates from the site (ie how fast the runoff is allowed to leave the site after development has taken place) should be controlled by maximising opportunities to capture runoff and slow flow rates through attenuation and flow controls (eg using swales, detention basins). Providing volumetric control measures (see above) can reduce the required downstream attenuation storage volumes (**Section 3.3.2**, water quantity standard 2).

Managing surface water runoff at or close to source helps prevent high rates and volumes of runoff being conveyed to large downstream attenuation systems.

There may be occasions, possibly in the lower reaches of large river catchments, where rapid discharge of runoff from the site would be a better strategy for managing flood risk than attenuation and slow release. If this can be demonstrated by detailed catchment modelling, this may be deemed appropriate by an approving body. This should be stated in the local flood risk management strategy and/or local supplementary planning documents.

3.2.4 Water quantity criterion 4: Preserve and protect natural hydrological systems on the site

Natural systems that deliver a specific hydrological function should be preserved and protected where possible, such as natural wetlands, stream and river corridors, high permeability soil features, areas of high water table, long-serving agricultural field ditches or ditch systems. Where such systems are dependent on particular runoff characteristics from the site, this should be taken into account within the SuDS design.

Where possible, clearing/grading/compaction should be limited, as these activities will have a negative effect on the natural runoff characteristics. Landscape and garden areas that have been compacted during construction should be returned to pre-construction permeability levels. Steep slopes or areas of the site with highly erodible soils should also be protected from additional runoff that could further destabilise material.

Local flood risk management strategies/river basin management plans may have strategic objectives for the management and/or improvement of local hydrological systems and may set local criteria for drainage systems that discharge to them.

Additional benefits of preserving natural hydrological systems can include the reduced need for cut and fill and the elimination of additional underground piping and pumping (**Section 8.5.3**).

3.2.5 Water quantity criterion 5: Drain the site effectively

A key requirement of the surface water management system is that it drains the site effectively. It should be designed with suitable gradients, so that there is a continuous flow of water through the system as any rainfall event drains through, allowing space for subsequent events to be stored and treated. Shallow gradients are usually suitable, particularly with surface features, and shallow gradients also help ensure that natural treatment processes work effectively.

The design of the drainage system should take account of the time that it is likely to take for the runoff to drain through the system. Considerations should include:

1 the impact of potential downstream constraints (eg high water levels in the receiving watercourse) on the rate and/or duration over which effective drainage can occur
2 the rate at which infiltration is likely to occur, which will determine the time taken for infiltration storage components to empty for any particular event
3 the hydraulic gradient across the site and the design of storage and conveyance components, which will determine the time taken for runoff to drain through the SuDS.

Where discharge from the site could be constrained because of high water levels at the outfall from the site, the likelihood of such water levels coinciding with design events for the drainage system should be evaluated and accounted for as part of the design process (**Chapter 24**).

Where any part of the drainage system is at risk of being inundated from external sources during extreme conditions, the impact of any potential loss of storage (from either inundation or sediment deposition) on the system performance should be assessed.

The impact of runoff from areas outside the site should be taken into account when sizing the drainage system. Such runoff should be safely routed around or across the site, but will not require additional control, unless this is part of planning or drainage approval requirements.

Guidance on designing SuDS on sites with steep slopes, with no gradient or very shallow slopes, and on floodplains is provided in **Chapter 8**.

3.2.6 Water quantity criterion 6: Manage on-site flood risk

The surface water management system should be designed to ensure that the level of flood risk from the drainage system is acceptable for the site (**Section 3.3.3**).

All runoff should remain within the designated conveyance and storage areas for the design (standard of service) event, including an appropriate freeboard allowance. The designated drainage system may include areas that are only designed to flood on an infrequent basis – for example car parks, roads, recreation areas – and such areas will need to be managed with this purpose in mind. For larger events, the site layout should be designed so that exceedance flows (ie flows that exceed the capacity of the drainage system) are managed in safe conveyance and storage zones, such that the risk of flooding is acceptable for all people and property on the site.

SuDS components that are on the surface provide the best means of seeing when water levels are starting to rise. This enables residents and other users of the site to take action early and effectively. The change in water level will tend to be gradual, as it moves out of the bank, providing more warning and reducing the likely severity of the consequences.

Managing the risks associated with external sources of flooding (river, surface water, groundwater etc) should be dealt with as part of the flood risk mitigation strategy (as defined by the Flood Risk Assessment or Flood Consequence Assessment). Further details are provided in **Chapter 7**. Any additional design requirements for the SuDS scheme as part of a site flood risk mitigation strategy would be over and above the requirements described in this manual.

3.2.7 Water quantity criterion 7: Design in system flexibility/adaptability to cope with future change

In order that the drainage system will continue to provide effective protection for both the site and downstream areas, throughout its design life, SuDS should incorporate sufficient capacity and/or be sufficiently adaptable so as to be resilient to climate change and increases in the level of urbanisation of the contributing catchment.

SuDS components are inherently more adaptable than fixed capacity, subsurface drainage infrastructure. In some cases where future ownership and investment capacity are assured, drainage systems might be designed with the flexibility for increasing capacity later in their design life, when climate change risks can be better quantified or when a higher level of service is required.

Otherwise, up-to-date rainfall intensity uplift factors for individual regions for climate change scenarios (**Section 24.7.1**) should be sourced from relevant ministerial or local government guidance, and incorporated within the design calculations to ensure the design is robust.

Increasing impermeability of the contributing catchment through the design life of the drainage system, should also be taken into account. Urban creep (ie the addition of patios, conservatories, extensions, impermeable driveways and other hardstandings) can be significant, particularly in low-to-medium-density developments, and an appropriate design factor should be agreed with the drainage approving body before drainage system design (**Section 24.7.2**).

3.3 WATER QUANTITY DESIGN STANDARDS

The following standards are standards of “good practice”. Local planning documents, national standards or other guidance from approving or adopting organisations may take precedence.

The research underpinning the standards on the use of peak flow rates and volume control of discharges is provided in Kellagher (2002).

BOX 3.1 Return periods, probability of occurrence and critical durations

The **return period** of a rainfall event is the average time between events of a given or greater magnitude, usually expressed in years. A 100-year return period event refers to an event that occurs or is exceeded on average once every hundred years. This can also be expressed as the 1 in 100 or 1:100 year event.

Alternatively, an event can be described as having a **probability of occurrence** (or frequency of occurrence), which is 1/return period but often expressed as a percentage. For a 1:100 year event, this would be 1%, ie there is a 1% chance of the event occurring or being exceeded in any one year.

Estimates of return periods are subject to uncertainty, so in reality, consecutive events can occur at intervals greater or smaller than their average return period. A 1:1 year event refers to an event that has a 100% chance of occurring in any one year, and thus could be interpreted as a range of events beneath a certain threshold. However, for the purpose of these standards, when referring to a 1:1 year event, this should be taken as meaning an event that occurs, on average, once a year.

The **critical duration** is the duration of rainfall event for a specified return period event (usually given in hours) that results in the greatest peak flow rate, flood volume or flood level (depending on the purpose of the analysis) at a particular location. It will be different for different locations on a site.

3.3.1 Water quantity standard 1: Control of runoff volume

The volume of runoff should be controlled for the following two scenarios:

a Volume control for frequent rainfall events

The drainage system should be designed so that runoff from the site to receiving surface waters does not occur for the majority of small rainfall events.

b Volume control for extreme rainfall events

The drainage system should be designed so that the volume of runoff discharged from the site during extreme events (normally specified as a 1:100 year event) is controlled.

Interpretation of this standard is presented as follows.

a) Volume control for frequent rainfall events

The prevention of runoff from the site for the majority of small (frequent) rainfall events (or for the initial depth of rainfall for larger events) is called **Interception**, and Interception of about 5 mm is normally achievable. From a hydraulic perspective, Interception is required to mimic greenfield hydraulic response characteristics where small rainfall events do not generally produce any runoff and thus to protect the morphology and ecology of the receiving watercourse, and the hydrological soil water balances in the catchment. Interception can be delivered using a variety of methods including rainwater harvesting, infiltration and evapotranspiration. Interception design methods are set out in **Section 24.8**.

This standard is the same as water quality standard 1 (**Chapter 4**). This is because the delivery of Interception provides both water quantity and water quality benefits. Compliance with this standard is not usually achievable during periods of wet weather, so a flexible approach is required (eg a requirement to achieve Interception for a given proportion of events during the summer and a lower proportion during the winter). In winter or during extended wet periods, the risks to the ecology and morphology of the receiving watercourse from urban runoff are likely to be lower.

b) Volume control for extreme rainfall events

Because the volume of runoff from the site can be, in many scenarios, as damaging to downstream flood risk as peak flow rates (Section 3.1), it is necessary to ensure that runoff volumes discharged from the site during extreme events are also controlled.

This means that, where possible, the volume of runoff from the site (or development) area should not exceed the volume of runoff from the equivalent area in its natural undeveloped or “greenfield” state (for the same rainfall event). Methods for estimating greenfield/pre-development runoff volumes are described in **Section 24.4**). Where flood risk from the receiving watercourse is particularly high, tighter local criteria for allowable volumes discharged from the site may need to be specified by the local regulator or drainage approving body and met by the drainage design.

The use of infiltration and rainwater harvesting are important mechanisms for delivering volume control: the greater the volume of runoff that is infiltrated or used on site, the lower the volume of runoff discharged. It is important to note that, for clay sites, greenfield runoff volumes will tend to be high because of the underlying impermeability. So the increase in volume for the developed site will be small. Where developments take place on more permeable soils, the difference will be far greater, but infiltration options should be available to assist in managing these larger volumes.

Ideally, the volumetric control of runoff should be demonstrated to meet greenfield runoff behaviour for all events and particularly those that are relevant for the mitigation of flood risk in the receiving watercourse. However, this would require the use of time series rainfall as part of a modelling exercise. Until this approach becomes standard industry practice, a simple method using the 1:100 year, 6 hour rainfall event can be sufficient for design purposes, as it represents a suitable event for protecting smaller watercourses that are most at risk from the effects of urban development. As designs for Interception will help control runoff volumes from smaller events, a single requirement for large events is considered pragmatic and not overly onerous.

Where controlling runoff to greenfield volumes is considered unachievable, then the runoff volume should be reduced as much as possible and any additional volume should be stored and released at a low rate that will not increase downstream flood risk (normally 2 l/s/ha is considered an appropriate rate (Kellagher, 2002)) using either of the following approaches*:

1 The additional runoff volume (ie the difference between the predicted development runoff volume and the estimated greenfield runoff volume for the 100 year event, often called **Long-Term Storage**) should be discharged from the site at a rate of 2 l/s/ha or less, while still allowing greenfield runoff peak flow rates to be applied for the greenfield runoff volume.

Note

* The 6 hour event can be used unless more detailed local catchment modelling has been undertaken to justify an alternative duration.

2 All the runoff from the site for the 1:100 year event should be discharged at either a rate of 2 l/s/ha or the average annual peak flow rate (ie the mean annual flood, QBAR), whichever is the greater.

Approach 2 provides a simpler approach, but results in larger storage volumes being required than Approach 1.

The calculation of the difference in volume between the developed and greenfield scenario (defined as the Long-Term Storage Volume) is set out in **Section 24.10**.

For previously developed sites, the surface water management system should be designed so that the volume of surface water runoff discharged from the site for the 1:100 year, 6 hour event is kept as close to greenfield conditions as possible. The runoff volume for the pre-development scenario may be very high and may be contributing to downstream flood risk – it should therefore only be allowed for the new development if the drainage approving body agrees that it is acceptable. Wherever runoff volumes cannot be sufficiently reduced, they should be discharged from the site at a rate of 2 l/s/ha or less (see above).

3.3.2 Water quantity standard 2: Control of peak rate of runoff

a Control peak runoff rates during events likely to impact on morphology, ecology or capacity of receiving surface waters, or capacity of receiving sewers

The drainage system should be designed so that peak runoff rates from the site for events likely to be significant for the morphology/ecology/capacity of receiving surface waters, or the capacity of receiving sewers (normally specified as approximately a 1:1 year event) are constrained to the greenfield rates of runoff for the same return period.

b Control peak runoff rates during extreme rainfall events

The drainage system should be designed so that the peak runoff rates for extreme rainfall events (normally specified as a 1:100 year event) are constrained to the greenfield rates of runoff for the same event.

The assessment of peak runoff rates and the design of attenuation storage systems is set out in **Sections 24.6 and 24.9**, respectively. The critical duration rainfall event should be used in determining the maximum attenuation storage volumes. Different critical durations will apply to different storage and conveyance elements used on the site.

Interpretation of this standard is presented as follows.

a) Control peak runoff rates during events likely to impact on morphology, ecology or capacity of the receiving surface waters, or the capacity of receiving sewers

A bankfull event for a stream or river tends to equate to about a 1:1 or 1:2 year event. By aiming to replicate greenfield runoff rates for this size of event, the receiving watercourse can be protected from erosion and the resulting morphological and ecological damage. For previously developed sites, site runoff rates should be reduced to the greenfield rates wherever possible.

By limiting discharges to sewers (and surface waters), this will reduce the impact on downstream capacity. If discharging to a combined sewer, this also reduces the impact on CSO spills and downstream wastewater treatment works.

For soils with relatively high permeabilities, the 1:1 year greenfield runoff rate may be considered too low to be feasible. In this case, a minimum throttle rate should be agreed by the drainage approving body. An appropriate limit is likely to be 1–2 l/s/ha. Guidance on controlling low flows is provided in **Chapter 28**.

b) Control peak runoff rates for extreme events to prevent surface water runoff from the site increasing downstream flood risk

Aiming to replicate greenfield runoff rates for extreme events helps ensure that the flood risk associated with the receiving watercourse/sewer is not increased by the development. Volume control (as required by water quantity standard 1) is also an important part of the flood risk mitigation approach.

For previously developed sites, site runoff rates should be reduced to the greenfield rates wherever possible. Because the critical duration for the attenuation storage system for the proposed development will be much longer than the storm duration used for sizing pipework for the previously developed site, there is a risk that by allowing previously developed runoff rates to occur (over a much longer duration) receiving watercourse damage and flood risk could be considerably worsened. Thus, betterment of at least 30% should be considered as a minimum requirement (this will need establishing and agreeing with drainage approving body) and strong consideration should still be given to controlling volumes of runoff to greenfield equivalents (**Section 3.3.1**).

3.3.3 Water quantity standard 3: Control of on-site flood risk arising from the surface water management system

a SuDS capacity design

There should not be any flooding on site for events up to the agreed drainage system capacity (standard of service – usually a minimum of a 1:30 year event), unless areas are specifically designed to do so.

b Exceedance capacity design

The risks associated with events that exceed the capacity of the drainage system should be evaluated, and the design of the site and the drainage system should be integrated so that flooding is appropriately managed.

a) SuDS capacity design

The SuDS should be designed so that runoff is completely contained within the **designated drainage system** for all events up to the specified standard of service for the critical duration event for the system (**Box 3.1**). This level of service will normally be 1 in 30 years as a minimum unless otherwise specified by or agreed with the planning approval or SuDS approving body. As peak runoff rates will usually require control up to the 1 in 100 year (see water quantity standard 2), components may be designed to manage events up to this size. The designated drainage system is the combination of the above-ground and below-ground components of the system (eg pervious pavements, swales, detention basins and pipes) that are designed to receive runoff during an event that equates to the specified standard of service.

Unless specific adaptation measures are agreed, the design rainfall for this scenario should include an allowance for climate change, and the assumed impermeable area for the site should include an allowance for urban creep (**Section 24.7**).

The critical duration rainfall event should be used. Different critical durations will apply to different parts of the site.

The layout of the development site and the SuDS scheme should be designed so that any surface water that enters the site from off-site sources is conveyed safely around or through the site, without compromising the level of service of the proposed drainage system or introducing unacceptable additional risks on site or downstream.

Where runoff from off-site sources is drained together with the site runoff, the contributing catchment should be modelled as part of the drainage system in order to take full account of the additional inflows.

Where runoff from off-site sources is conveyed separately from the proposed drainage system, any flood risks associated with this source should be managed appropriately. This should be dealt with in the Flood Risk Assessment (FRA) (or Flood Consequence Assessment, FCA) and associated management strategy for the site.

b) Exceedance capacity design

Properties should be fully protected against flooding from the site drainage system for the 1:100 year event. Higher return periods may be specified for particular catchments or locations and this should be established by the FRA/FCA for the site. In Scotland, the standard requirement is for 1:200 year protection. The design rainfall for this scenario should include an allowance for climate change, and the assumed impermeable area for the site should include an allowance for urban creep (**Section 24.7**). The critical duration rainfall event should be used. Different critical durations will apply to different parts of the site.

The finished ground floor levels and the level of any opening into any basement of the proposed buildings on the site should be at least 300 mm above the predicted flood level associated with the above scenario – or as otherwise specified by the drainage approving body and confirmed within the site FRA/FCA.

Access should be provided into and through the site for emergency vehicles for extreme runoff events and where the site could be flooded from other sources.

The design of the drainage system for exceedance flow management should take account of any residual flood risks for the site that are identified by the FRA/FCA. An assessment should also be made of the potential significance of risks associated with the following scenarios:

1 a blockage or failure of any key component or structure
2 failure of any embankment that forms part of a storage component
3 rainfall events that are larger than the design storms used for the design of the drainage system

Where any of these scenarios are considered to present a significant risk for the site, a risk assessment should be undertaken to determine adequate risk mitigation measures.

When assessing the risks associated with conveyance routes or storage areas for exceedance flows, flow depths, velocities, duration and impact of the flooding to people and property on and off the site should be taken into account. Further guidance on designing for exceedance in urban drainage can be found in Digman *et al* (2006 and 2014).

3.4 REFERENCES

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Image courtesy Studio Engleback

4 DESIGNING FOR WATER QUALITY

Contents

Chapter 04

Designing for water quality

This chapter explains the objective of designing for water quality and the design criteria that should be followed to deliver this objective. Good practice design standards are also presented.

- ▶ *This chapter should be read alongside Chapters 3, 5 and 6 to understand how the different SuDS design criteria relate to each other and Chapter 7 to understand when and how to apply these criteria.*
- ▶ *Guidance on designing individual SuDS components for treatment can be found in Chapters 11–23.*
- ▶ *Information regarding urban runoff contaminants, together with methods for assessing level of hazard, is presented in Chapter 26.*

4.1 WATER QUALITY DESIGN OBJECTIVE

Manage the quality of runoff to prevent pollution

Diffuse urban pollution (ie pollution from widespread multiple sources – see **Chapter 1**) is a significant factor in compromising groundwater and receiving water standards that are required under the EU Water Framework Directive. The UK government recognises that tackling diffuse pollution originating from urban runoff is a high priority and the increased use of SuDS is an important means of reducing urban runoff and improving the water quality of that runoff (Defra, 2012).

Agricultural land can also be a significant source of pollution, but this is not covered by this manual. Guidance on SuDS for agricultural sites is provided by Avery (2012).

Pipes are usually designed to convey water at velocities that keep sediment in suspension, preventing build-up within the pipe but transferring the runoff and any associated pollution directly to the receiving surface waters. Although some gullypots and catchpits can trap sediment, their efficacy is strongly linked to the frequency of maintenance, and there are significant risks associated with poor-quality water that is stored in them being remobilised and washed downstream. SuDS can treat and clean surface water runoff from urban areas so that the receiving environment is protected, while at the same time conveying, storing and infiltrating surface water to protect flood risk, river morphology and water resources, and delivering amenity and biodiversity value for the development.

There is large variability in the level of pollutants in urban runoff. Sources of pollution from impermeable surfaces are summarised in **Table 4.1**. Evidence relating to urban runoff pollution is presented in **Section 26.4**. Untrafficked areas are usually the least contaminated, with levels of contamination tending to rise with traffic intensities (particularly manoeuvring frequencies and lorry movements) and with higher risks of spillages and process contaminants from commercial and/or industrial activities.

Factors affecting pollution levels in urban runoff are set out in **Box 4.1**, with antecedent weather conditions (which affects the build-up of contaminants on the surface) and rainfall characteristics influencing the amount of pollution washed off the site in any individual rainfall event.

Information regarding urban runoff contaminants is presented in **Chapter 26 (Annex 1)** together with methods for assessing the level of hazard posed (**Section 26.7**).

BOX 4.1 Factors influencing pollution levels in urban runoff

The amount and type of pollution washed off a surface will depend on many things including:

- planned activities on, above and adjacent to the surface that affect the deposition of pollutants, their retention on the surface and the extent to which they are mixed with runoff (including pollution prevention strategies – see **Chapter 27**)
- unplanned activities (accidents and spillages) that can cause temporary unexpected high pollutant concentrations – such as from a road accident or poor pollution prevention practices on construction sites, housing estates, commercial and industrial zones or waste management areas
- the surface location and type, affecting wash-off rates and contaminant movement mechanisms
- the drainage path
- the length of the dry weather period before the rainfall event
- the intensity and duration of the rainfall, and the associated flow velocities
- any further pollutant transformations occurring during residence and conveyance within gullies, chambers, pipe or channel networks, gravels, soils and vegetation and quiescent bodies of water.

The pollution risk posed by the site will depend on the sensitivity of the receiving environment, the pathway between the source of the runoff and the receiving waters, and the level of dilution available. The variety, scale and complexity of diffuse urban pollution can potentially lead to a range of intermittent acute (short-term) impacts and chronic (longer-term) impacts.

The overall impact of the site on water quality in the receiving waters is dependent on the following:

- the **types of pollutants** on the site, as these have different effects on the receiving water body (**Table 4.1**)
- the **peak pollutant concentrations** in the runoff from the site, as these can cause acute (short-term) toxicity in the receiving waters
- the **total pollutant load** likely to be conveyed in the runoff from the site to the receiving environment, as this can cause chronic (long-term) pollution and gradual deterioration, owing to cumulative build-up of pollutants.

The relationship between peak pollutant concentrations and total pollutant load is discussed in **Box 4.2**.

Potential impacts on receiving surface waters include the blanketing of river beds with sediment and the reduction of light penetration from suspended solids causing negative impacts on ecosystems. In some cases, this can result in the slow decline in biodiversity and ultimately the “death” of the river.

Dissolved pollutants and hydrocarbons can lead to reductions in natural oxygen levels in surface waters, toxic conditions, metals bioaccumulation, contamination of benthic organisms, and the death of fish and other animals. In extreme cases (often because of misconnections with the foul sewerage system), significant levels of pathogens may also be present in the runoff, and these can be hazardous to human health in the event of exposure.

Pollution of groundwater, although less obvious than pollution of surface waters, tends to be irreversible and permanent. Groundwater quality is at risk from both point source pollution (eg a leak from an oil storage tank) and diffuse pollution (eg leaking sewers or infiltration of contaminated runoff). Good quality groundwater is crucial for water-dependent plants and animals, and as a source of drinking water. Nitrates, pesticides, solvents, metals, hydrocarbons and other pollutants can potentially find their way into groundwater with the level of risk posed depending on the following:

- **The type of pollutant.** Trace metal contaminants are conservative and will ultimately migrate through the unsaturated zone – the soil layer between the land surface and the groundwater level. Organic and some inorganic compounds, however, have the potential to undergo degradation as they pass through the soil. Usually biodegradation is the most important process affecting organic compounds, but other processes such as hydrolysis, reduction and substitution may be relevant to specific compounds and subsurface environments.
- **The depth of the unsaturated zone.** Greater depths will tend to increase the time taken for contaminants to migrate down to groundwater and potentially reduce the contaminant concentrations at this point, where degradation processes occur in the soil profile.
- **The characteristics of the unsaturated zone.** Some soils will provide better contaminant retention and storage, increasing the length of time before contaminants migrate down through the soil to groundwater, and better facilitating contaminant degradation. For example, fine grained materials will provide a better barrier to pollutant migration than materials with fissure or fracture flow paths.
- **The level of build-up of contaminants within the soil profile.** This will be a function of the contaminant loading rate and the length of time over which contaminants have accumulated. Higher loading rates are likely to reduce the period over which contaminants are retained within the soils and prevented from downward migration.

It is therefore important to design drainage systems to protect both surface waters and groundwaters, by assessing the potential risk posed by the site and putting in place adequate measures to reduce the risk to acceptable levels (**Section 4.2.2**). This helps ensure that all discharges meet the requirements of relevant legislation, and that discharges from SuDS are sufficiently low risk that they will not require “permitting” or “licensing” by the environmental regulator.

Designing for water quality using a risk-based approach is discussed in **Section 4.2**.

BOX 4.2 **Pollutant concentrations and loads**

A peak "flush" of pollutants often occurs during the early stages of a storm event, before the flow rate in the system reaches its peak. It is possible to get a high initial pollution concentration for relatively small rainfall events, as it does not take a great deal of rain to wash off the pollutants. This is why it is important to manage the frequent small events effectively.

Figure 4.1 shows how pollution concentration (red) and cumulative pollution load (green) change over time for sediments transported during a rainfall event, compared to the flow rate (blue). This shows the initial "flush" of pollutants shortly after the start of the event, and then there is a second peak later in the event, which coincides with a further increase in flow rate, as runoff from more distant parts of the site reaches the downstream system.

These peaks in sediment concentration are typical of sediments transported from urban surfaces and also for the pollutants that are predominantly attached to the sediments during an event, such as hydrocarbons, organic compounds and heavy metals. Other pollutants (including dissolved pollutants) can show different runoff patterns, but all show high initial concentrations due to initial wash-off of pollutants from the catchment surface.

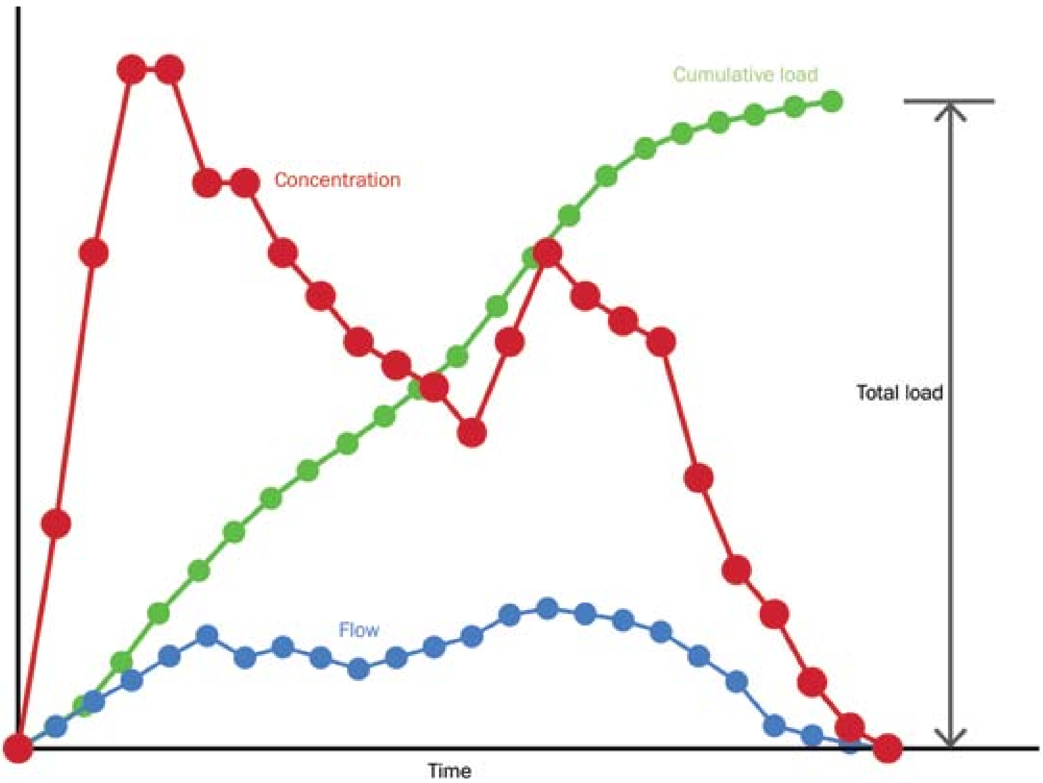

Figure 4.1 Example of flow, pollutant concentration and pollutant load build-up during a rainfall event

TABLE 4.1 Sources of pollution from impermeable surfaces (after Wilson *et al*, 2004)

Source	Typical pollutants	Source details
Atmospheric deposition	Phosphorous, nitrogen, sulphur, heavy metals[1], hydrocarbons, particulates	Industrial activities, traffic air pollution and agricultural activities all contribute to atmospheric pollution. Rain also absorbs atmospheric pollutants, which are then present in runoff. Atmospheric pollutants can be deposited on, or absorbed by roofing materials and discharged into roof runoff – flat urban roofs are particularly vulnerable.
Traffic – exhausts	Hydrocarbons, MTBE[2], cadmium, platinum, palladium, rhodium	Vehicle emissions include polycyclic aromatic hydrocarbons (PAH) and unburnt fuel and particles from catalytic converters.
Traffic – wear and corrosion	Particulates, heavy metals[1]	Abrasion of tyres and corrosion of vehicles deposit pollutants onto the road or car parking surfaces.
Leaks and spillages (eg from road vehicles)	Hydrocarbons, phosphates, heavy metals[1], glycols, alcohols	Engines leak oil, hydraulic and de-icing fluids and spillages occur when refuelling. Lubricating oil can contain phosphates and metals. Accidental spillages also occur.
Litter/animal faeces	Bacteria, viruses, phosphorous, nitrogen	Litter typically includes items such as drinks cans, paper, food, cigarettes, animal excreta, plastic and glass. Some of this will break down and cause pollutants to be washed off urban surfaces. Dead animals on roads decompose and release pollutants including bacteria. Pets and other animals leave faeces that wash into the drainage system.
Vegetation/ landscape maintenance	Phosphorous, nitrogen, herbicides, insecticides and fungicides, organic matter	Leaves and grass cuttings are an organic source. Herbicides and pesticides used for weed and pest control in landscaped areas such as gardens, parks, recreation areas and golf courses can be a major source of pollution.
Soil erosion	Sediment, phosphorous, nitrogen, herbicides, insecticides and fungicides	Runoff from poorly detailed landscaped or other areas can wash onto impervious surfaces and cause pollution of runoff.
De-icing activities	Grit, chloride, sulphate, heavy metals[1], glycol, cyanide, phosphate	Salt is commonly used for de-icing roads and car parks. Rock salt used for this purpose comprises sodium chloride and grit. It can also include cyanide and phosphates for anti-caking and as corrosion inhibitors, heavy metals, urea and ethylene glycol.
Cleaning activities	Sediment, phosphorous, nitrogen, detergents, hydrocarbons	Washing vehicles, windows, bins or pressure washing hardstandings leads to silt, organic matter, detergents and hydrocarbons (mobilised by the detergents) entering the surface water drainage.
Sewer misconnections	Bacteria (including pathogens), detergents, organic matter and textiles	Accidental (but illegal) connections of foul sewers to surface water sewers – where separate sewers exist.
Illegal disposal of chemicals and oil	Hydrocarbons, various chemicals	Illegal disposal of used engine oils or other chemicals can occur at small (domestic) or large (industrial) scales.

Note

1 Heavy metals include: lead, cadmium, copper, chromium, nickel, zinc, mercury. Not all heavy metals are present in all cases.

2 Methyl tert-butyl ether.

4.2 WATER QUALITY DESIGN CRITERIA

4.2.1 Summary

The design criteria presented here should be applied to manage the quality of runoff to support and protect the natural environment effectively. Managing water quality can also contribute to the design criteria for water quantity, amenity and biodiversity and, therefore, should be considered alongside these (see **Chapters 3, 5 and 6**).

Indicators can be used to evaluate the extent to which these design criteria are being delivered by a SuDS design. Water quality design criteria and example indicators are presented in **Table 4.2**.

TABLE 4.2 Water quality design criteria and example indicators

Water quality design criterion	Example indicator
1 Support the management of water quality in receiving surface waters and groundwaters	The extent of pollution prevention activities in the catchment (**Chapter 27**) The extent to which appropriate risk management measures for spillages are in place The proportion of permeable surfacing, green roofs, and/or surfacing that discharges to a rainwater harvesting system or soil-based feature Delivery of Interception and treatment to meet the standards set out in **Section 4.3** The proportion of the surface water management system that is on or near the surface and facilitates treatment The extent to which the design of the system demonstrates attention to sediment retention, such as forebays or hydrodynamic separators
2 Design system resilience to cope with future change	The design of the system includes allowances for climate change and urban creep

These design criteria are discussed in more detail in following subsections. Where minimum performance targets or specific levels of service should be achieved by a SuDS design, these are detailed in **Section 4.3**, and guidance is provided as to how these can be met. Regional or local standards as set out in adopted supplementary planning documents (SPDs) may take precedence.

4.2.2 Water quality criterion 1: Support the management of water quality in receiving surface waters and groundwaters

To protect the water quality of receiving surface waters and groundwaters effectively (both now and in the future), runoff discharged from the site should be of an acceptable water quality. Even where a receiving water already contains elevated levels of pollutants, and the surface water discharge is unlikely to have a significant impact, pollutants generated by site activities should be managed on site. This helps ensure that current or future water quality objectives for the receptor are not compromised and that risks associated with acute (temporary and unexpected high contaminant loadings) are minimised.

Pollution control can be achieved through:

- **Pollution prevention:** stopping contaminants becoming mixed with runoff, for example road sweeping, preventing misconnections, bunds for oil tanks, controlling sediment. Where pollution prevention is a fundamental part of environmental protection, it should deliver predictable and guaranteed outcomes. This is normally only achievable on sites where the site operator is also responsible for the drainage system and any downstream pollution, such as on industrial sites. Community strategies are valuable in reducing risks to downstream SuDS performance, but as these are voluntary, such strategies cannot be relied upon to deliver the required outcome. Pollution prevention strategies are discussed in detail in **Chapter 27**.

- **Interception:** preventing runoff (and the associated pollution load) from the majority of small rainfall events, for example through the use of pervious surfaces and vegetated collection systems. Interception helps facilitate the retention of pollutants in surface vegetation, soil or other material layers from where a proportion can often be degraded. This can reduce the potential total pollution load discharged to the receiving surface waters over the year (noting that risks to groundwater should always be managed effectively). The requirement for Interception is set out as water quality standard 1 in **Section 4.3.1**. It is also required by water quantity standard 1 in **Section 3.3.1**, and guidance on designing for Interception is set out in **Section 24.8**.
- **Treatment:** implementing SuDS components (in series where required) that use a range of treatment processes to reduce contaminant levels in the runoff to acceptable levels. Treatment components will often deliver Interception and usually also meet conveyance and storage requirements. The requirement for treatment is set out as water quality standard 2 in **Section 4.3.2**. Guidance on designing a treatment system is set out in **Section 26.8**.
- **Maintenance and remedial work** to remove captured pollutants and maintain system performance (**Chapter 32**).

Treatment design, wherever practicable, should be based on the good practice described in **Box 4.3**. The opportunities for a designer to apply these practices in full will be dependent on site characteristics, development context and local planning objectives. To maximise the opportunities afforded by these approaches, they should be considered at an early stage of the design process and fully integrated into that process.

The wide range and levels of contaminants in surface runoff, together with the natural variability associated with SuDS pollution removal processes (**Section 26.6**) means that water quality needs to be managed using a robust, risk-based approach. This is usually facilitated via a SuDS Management Train of a number of components in series that provide a range of treatment processes delivering gradual improvement in water quality and providing an environmental buffer for accidental spills or unexpected high pollutant loadings from the site (**Section 26.8**). In some cases, it may be possible to deliver the appropriate risk management using a single component, where this has been designed to deliver the required pollution control for the range of expected contaminants.

The most appropriate approach for managing pollution on any site often depends on how the site is split up in terms of ownership or use, the layout and characteristics of the development and the best ways of delivering the quantity, amenity and biodiversity design criteria (**Chapters 3, 5 and 6**).

Managing pollution close to its source can help keep pollutant levels and accumulation rates low – allowing natural treatment processes to be effective. This can help maximise the amenity and biodiversity value of downstream surface SuDS components and can keep maintenance activities straightforward and cost-effective. Where a site is owned or used by more than one individual or organisation (eg on commercial/industrial sites), it allows sources of pollution to be traced and controlled, so the location of SuDS components on a site can be fundamental to their success in managing pollution. Treatment can often be delivered within the same components that are delivering water quantity design criteria, hence requiring no extra cost or land-take.

BOX 4.3 **Good practice for SuDS treatment design**

1 Manage surface water runoff close to source

Where practicable, treatment systems should be designed to be close to the source of runoff. The advantages of this approach from a water quality perspective are as follows:

- It is easier to design effective treatment when the flow rate and pollutant loadings are relatively low.
- The treatment provided can be proportionate to the pollutant loadings, ie parts of the site with low pollutant loads do not need to have as much treatment as highly polluting parts of the site.
- Accidental spills or other pollution events can be isolated more easily and dealt with effectively without affecting the downstream drainage system.
- It encourages ownership of pollution, for example having treatment delivered on individual plots (where responsibility for performance and maintenance of the SuDS component(s) lies with the property owner) or adjacent to specific lengths of road.
- Poor treatment performance or component damage/failure can be isolated more easily and dealt with effectively without impacting on the whole site.

2 Treat surface water runoff on the surface

Where practicable, treatment systems should be designed to be on the surface. The advantages of this approach from a water quality perspective are as follows:

- Where sediments are exposed to UV light, photolysis and volatilisation processes can act to break down contaminants – specifically oils and other hydrocarbons.
- If sediment is trapped in accessible parts of the SuDS, it can be removed easily as part of routine landscape maintenance work.
- It enables use of evapotranspiration and some infiltration to the ground to reduce runoff volumes and associated total contaminant loads (ie Interception), provided that the risk to groundwater is managed appropriately (**Section 26.7**).
- It allows treatment to be delivered by vegetation.
- Sources of pollution can be easily identified.
- Accidental spills or misconnections are visible immediately and can be dealt with rapidly.
- Poor treatment performance or component damage/failure is easily identified during routine inspections, and remedial works can be planned efficiently.

3 Treat surface water runoff to remove a range of contaminants

The SuDS design should consider the likely presence and significance of any contaminant that may pose a risk to the receiving environment, and the SuDS component or combination of components selected should include treatment processes that, in combination, are likely to reduce this risk to acceptably low levels.

4 Minimise risk of sediment remobilisation

The SuDS design should consider and mitigate the risks of sediments (and other contaminants) being remobilised and washed into receiving surface waters (or onto surfaces through which runoff is designed to infiltrate) during events greater than those for which the treatment component has been specifically designed. Guidance is provided in each of the technical component chapters (**Chapters 11–23**).

5 Minimise impacts from accidental spills

By using a number of components in series, SuDS design can help ensure that accidental spills are trapped in/on upstream component surfaces, facilitating contamination management and removal. The selected SuDS components should deliver a robust treatment design that manages the risks appropriately – taking account of the uncertainty and variability associated with both the pollution loadings and the treatment processes.

4.2.3 Water quality criterion 2: Design system resilience to cope with future change

In order that the drainage system will continue to provide effective management of runoff to support and protect the natural environment, SuDS treatment designs should take account of the potential impacts of climate change on the system processes and associated performance, and consider measures/approaches that aim to make the system more resilient.

Key projected climate changes relevant for treatment systems are increases in ambient temperatures and reduced rainfall during the summer – both of which may affect the survival or success of some types of plants. Increased temperatures of runoff can also be damaging to sensitive ecosystems, but this risk should be mitigated to some extent through the use of SuDS.

It is less important to design in system resilience to manage increased runoff (for water quality management), due to the focus on preventing and/or treating relatively low flows.

4.3 WATER QUALITY DESIGN STANDARDS

The following are standards of "good practice". Local planning documents or national standards may take precedence.

4.3.1 Water quality standard 1: Prevent runoff from the site to receiving surface waters for the majority of small rainfall events

No runoff should be discharged from the site to receiving surface waters or sewers for the majority of small (eg < 5 mm) rainfall events. This is termed **Interception**.

This standard is the same as water quantity standard 1a (**Section 3.3.1**). This is because the delivery of Interception provides both water quantity and water quality benefits.

Runoff from small rainfall events can pose a particular problem for water quality in receiving surface waters because:

- it contains the initial flush of pollutants that has built up on surfaces during the preceding dry period (**Box 4.2**)
- there are many more smaller rainfall events than larger ones, leading to frequent flushing of pollutants from surfaces
- the volume of runoff from all small rainfall events tends to comprise a significant proportion of the total runoff volume in any given period, and together with the relatively higher pollution concentrations, can contribute significantly to total pollutant loadings from the site over a specified period of time.

Retaining these regular events and their pollutant loads on site will help protect receiving surface waters against ongoing chronic pollution risks and contaminant accumulation. Where Interception includes infiltration, even though volumes may be small, the protection of groundwater should be fully considered and any risks managed to acceptable levels (**Section 26.7**). Although a proportion of pollutants retained within SuDS components in soils is likely to be degraded, some pollutants are likely to build up over time. Therefore, these may need removing during routine maintenance (eg sediments from sediment removal components) or as part of component rehabilitation (eg when the capacity of soil layers to retain pollutants has been exhausted, although this is unlikely to be required during the design life of the development, if the drainage system is designed correctly – see Scott Wilson, 2010).

Rainfall events that are less than or around 5 mm in depth comprise more than half of all rainfall events across the UK. On natural catchments, such events rarely produce any runoff at all. However, on impermeable catchments, runoff tends to be generated for almost all events. The hydraulic drivers for designing drainage systems that retain and prevent runoff from the first 5 mm of rainfall for the majority of rainfall events, are set out in **Chapter 3** and include protecting the receiving surface waters from morphological and associated ecological damage from unnatural regular surface water discharges.

Interception can be delivered via rainwater harvesting systems, green roofs, infiltration systems, pervious surfaces and vegetated SuDS. By using the storage available in soil or aggregate matrices, together with evapotranspiration and infiltration processes, many components can intercept 5 mm of rainfall for contributing surfaces several times greater than their own surface area. Interception design methods are set out in **Section 24.8**.

Requiring Interception for the "majority" of events recognises that once soils are saturated (mainly during or following long periods of wet winter weather) runoff will occur, and drainage systems cannot be expected to prevent this. Events that follow on quickly from a previous event may also not be completely captured by a drainage system designed for Interception.

Maximising Interception in the summer months is particularly important for protecting receiving surface waters. Runoff during the summer months can cause greater problems for receiving surface waters than runoff in winter months, due to low flows in the receiving surface water. Limited dilution of pollutants within runoff and within the receiving surface water receptor may cause increased localised pollutant impact.

4.3.2 Water quality standard 2: Treat runoff to prevent negative impacts on the receiving water quality

Runoff should be adequately treated to protect the receiving water body from:

1. **Short-term acute pollution** that may result from accidental spills or temporary high pollution loadings within the catchment area.
2. **Long-term chronic pollution** from the spectrum of runoff pollutant sources within the urban environment.

The extent of treatment required will depend on the land use, the level of pollution prevention in the catchment (**Chapter 27**) and for groundwater the natural protection afforded by underlying soil layers. High hazard sites will have a higher potential pollution load and higher potential maximum pollution concentrations. They will therefore tend to require more treatment than low hazard sites in order to deliver discharges of an acceptable quality. The land use will also dictate the likely significance of different types of contaminants in the runoff, and this may influence the treatment processes that need inclusion within the treatment system. The treatment processes provided by different SuDS components will have varying capabilities to remove different types of contaminants.

Most sites will be relatively low risk, and the risk can be mitigated by implementing SuDS components close to the source of runoff and in sequence where higher levels of protection are required (ie the SuDS Management Train). SuDS components usually offer a range of treatment processes and, in sequence, deliver gradual improvements in water quality, as well as providing an environmental buffer for accidental spills or unexpected high pollutant loadings from the site

▶ Guidance on designing a treatment system using a SuDS Management Train is provided in **Section 26.8**.

Discharges to receiving waters that are close to a drinking water abstraction point may require greater protection, so an extra treatment component (over and above what is sufficient for standard discharges) may be required in the SuDS Management Train to adequately manage the risks associated with unexpected temporary high pollution loadings and/or poor system performance.

In England and Wales, reference to local planning documents should also be made to identify any further protection required for sites due to habitat conservation (**Chapter 7**). The implications of developments on or in close proximity to an area with an environmental designation, such as a site of special scientific interest (SSSI), should be considered via consultation with relevant conservation bodies such as Natural England.

Discharges from some land uses (eg industrial sites) may be considered particularly high risk – in which case the drainage system will need to be designed to meet the requirements established by a site-specific risk assessment (**Section 26.7.3**) and agreed with the environmental regulator. Design solutions will depend on the level of risk and may include one or more of the following:

- an additional SuDS component in the Management Train or an active intervention (eg stopcock, penstock or other control structure that is watertight at low hydraulic heads) to adequately manage the risks associated with spillages (acute pollution), poor system performance (eg due to seasonal impacts), the inherent performance variability of natural systems and/or delays in effecting maintenance
- a bespoke treatment system where the range, type and level of the contaminants and the performance of the system in managing the contaminants is well understood – in such scenarios, ongoing monitoring of the system will often be required
- prevention of the discharge (eg by covering the activity and draining the area to the foul sewer) or site-specific pollution prevention strategies.

The requirements for discharges to surface waters need to be considered where the runoff from frequent events (eg up to about a 1:1 year event) is conveyed via the drainage system to a receiving surface water body. The design water quality event for components that treat runoff as it flows through media or vegetation is usually set as the 1 year, 15 minute (or other relevant critical duration) event. For ponds the design water quality event is usually set as a depth of rainfall (**Section 23.5**). Where discharges to surface waters will only occur for larger events, pollution risks are generally not considered significant, and treatment is generally not required (although this should be checked on a site-specific basis with the environmental regulator).

With respect to the requirements for discharges to groundwater, the environmental regulators in different parts of the UK take different approaches to the level of infiltration considered to pose a potential risk:

- In England and Wales, the requirements for discharges to groundwater should be considered wherever there is a chance of infiltration, even when this will only be in small amounts (eg from the base of conveyance swales and detention basins), as well as for components designed specifically for infiltration.
- In Scotland and Northern Ireland, the requirements for discharges to groundwater only need to be considered where components are designed specifically for infiltration (eg soakaways, infiltration trenches, infiltration basins).

Groundwater protection is required for any event > 1 year where the runoff is discharged via infiltration.

The following points should be noted when using **Table 4.3**:

Discharges to either surface waters and/or groundwater

1 If the specific land use associated with the catchment to be drained is not given in the table, then guidance on the appropriate approach should be sought from the environmental regulator.

2 Contaminated runoff from areas handling hazardous or highly polluting materials, such as food waste, chemical and fuel handling areas, animal management and agricultural facilities*, vehicle refuelling or washing operations should be minimised (eg by covering) and any wash-off that is generated should be drained to an appropriately maintained and managed, sealed and discrete disposal solution, such as the foul sewer. The protection of nitrate-vulnerable zones is also likely to be relevant (**https://www.gov.uk/nitrate-vulnerable-zones**).

* Note that in England, guidance on rural SuDS is provided by Avery (2012).

3 Developments such as industrial sites, waste management sites and lorry and bus/coach parking or turning areas need to be discussed as part of pre-permitting discussions with the environmental regulator, and they may need authorisation (**Box 4.4**). In such circumstances SuDS may still be appropriate, but the design of the system will be dependent on the outcomes of a site-specific risk assessment (**Section 26.7.3**).

Discharges to groundwater only

1. The discharge of clean roof water to the ground is acceptable provided that (a) all roof water downpipes are sealed against pollutants entering the system from polluted surface runoff, effluent disposal or other forms of discharge and (b) gross sediments and silts are removed upstream of the infiltration component.
2. There should be a minimum depth of 1 m of unsaturated aquifer material between the base of any infiltration system and the maximum likely groundwater level (taking account of potential shifts in groundwater level resulting from extended periods of wet weather). Evidence from groundwater records may demonstrate the maximum groundwater levels, but where there is any uncertainty, appropriate groundwater monitoring should be undertaken to demonstrate levels across the site. Ground investigation should establish the typical maximum upper level of the saturated layer of an unconfined aquifer. "Typical" in this context would be a representative winter water table level, based on hydrogeological records and/or expert opinion and discounting extremes in weather or artificial suppression by engineering techniques such as pumping.
3. The method of discharge should not create new pathways for pollutants to groundwater or mobilise contaminants already in the ground (EA, 2013).
4. For contaminated land sites, the site investigation report should be used to identify any residual hotspots where pollutants are still likely to be present, and these areas should be located on the site plan. Any infiltration through contaminated soils could potentially mobilise or remobilise pollutants, alter remedial measures undertaken on site and cause pollution of groundwater. Guidance on an appropriate approach for this should be sought from the environmental regulator. A discharge that disturbs land that subsequently causes a release of pollutants to groundwater may potentially require an environmental permit, or alter liabilities under Part IIa of the Environmental Protection Act 1990. Guidance on designing SuDS for contaminated land sites is included in **Section 8.2**.

BOX 4.4 UK regulations for discharges to groundwaters

The regulators in England and Wales should be consulted if a discharge meets the definition of a groundwater activity under the Environmental Permitting (England and Wales) Regulations 2010 and does not meet an appropriate exemption.

In Northern Ireland, a discharge consent, groundwater authorisation or pollution prevention and control (PPC) permit may be required for surface water discharges to the ground.

In Scotland, an authorisation under the Water Environment (Controlled Activities) (Scotland) Regulations (CAR) 2011 or a pollution prevention and control (PPC) permit may be required. In Scotland, certain discharges to surface waters are automatically authorised by general binding rules (GBR). In such cases, it is not necessary to apply for authorisation from SEPA, but the design and discharge must comply with the conditions of the GBR.

TABLE 4.3 Minimum water quality management requirements for discharges to receiving surface waters and groundwater

<table>
<tr><th>Land use</th><th>Pollution hazard level</th><th>Requirements for discharge to surface waters, including coasts and estuaries[2]</th><th>Requirements for discharge to groundwater</th></tr>
<tr><td>Residential roofs</td><td>Very low</td><td colspan="2">Removal of gross solids and sediments only</td></tr>
<tr><td>Individual property driveways, roofs (excluding residential), residential car parks, low traffic roads (eg cul de sacs, home zones, general access roads), non-residential car parking with infrequent change (eg schools, offices)</td><td>Low</td><td colspan="2">Simple index approach[3]
Note: extra measures may be required for discharges to protected resources[1]</td></tr>
<tr><td>Commercial yard and delivery areas, non-residential car parking with frequent change (eg hospitals, retail), all roads except low traffic roads and trunk roads/motorways</td><td>Medium</td><td>Simple index approach[3]
Note: extra measures may be required for discharges to protected resources[1]</td><td>Simple index approach[3]
Note: extra measures may be required for discharges to protected resources1
In England and Wales, Risk Screening[4] must be undertaken first to determine whether consultation with the environmental regulator is required.
In Northern Ireland, the need for risk screening should be agreed with the environmental regulator.</td></tr>
<tr><td>Trunk roads and motorways</td><td>High</td><td colspan="2">Follow the guidance and risk assessment process set out in HA (2009)</td></tr>
<tr><td>Sites with heavy pollution (eg haulage yards, lorry parks, highly frequented lorry approaches to industrial estates, waste sites), sites where chemicals and fuels (other than domestic fuel oil) are to be delivered, handled, stored, used or manufactured, industrial sites</td><td>High</td><td colspan="2">Discharges may require an environmental licence or permit[3]. Obtain pre-permitting advice from the environmental regulator. Risk assessment is likely to be required[5].</td></tr>
</table>

Notes

The minimum water quality management requirements for discharges to receiving surface waters and groundwater are presented here. (For Northern Ireland, this guidance should be considered as interim until such time as Northern Ireland publishes its own legislation/policy/guidance.)

1 These are not required in Scotland and Northern Ireland. For England and Wales, see Step 3 of the simple index approach (**Section 26.7.1**).

Protected surface water resources will include those designated for drinking water abstraction or for other environmental protection reasons. Protected groundwater resources are represented by SPZ1s in England and Wales.

2 In Scotland, the Water Environment (Controlled Activities) (Scotland) Regulations (CAR) 2011 General Binding Rules, Rule 10 (d) (iv) effectively provides an exemption from requiring SuDS for coastal discharges. However, control of any contaminants likely to be present in surface water runoff is still required, but can be delivered using alternative methods such as proprietary treatment products. As the term 'SuDS' in this manual includes proprietary treatment products, this exemption is not valid in this context.

3 The application of the simple index approach should follow the approach outlined in **Section 26.7.1** (or equivalent approved).

4 Risk screening is an assessment to identify high risk scenarios where the Environment Agency or Natural Resources Wales (NRW) would wish to be consulted regarding infiltration of water from surface runoff in order to agree the proposed design approach. The risk screening method is provided in **Section 26.7.2**.

5 The risk assessment should determine the appropriate design approach to mitigate risk to acceptable levels following the guidance outlined in **Section 26.7.3**. This assessment should be approved by the environmental regulator.

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Image courtesy Studio Engleback

5 DESIGNING FOR AMENITY

Contents

Chapter
05

Designing for amenity

This chapter explains the objective of designing for amenity, and the design criteria that should be followed to deliver this objective.

- *This chapter should be read alongside Chapters 3, 4 and 6 to understand how the different SuDS design criteria relate to each other, and Chapter 7 to understand when and how to apply these criteria.*
- *Further discussion on designing for amenity specifically within the urban context can be found in Chapter 10.*

5.1 AMENITY DESIGN OBJECTIVE

Create and sustain better places for people

Good urban design aims to deliver attractive, pleasant, useful and above all "liveable" urban environments that support and enhance local communities (**Box 5.1**). Water is a valuable natural resource, and the management of rainfall and runoff can form a key part of an urban vision. Designs using surface water management systems to help structure the urban landscape can enrich its aesthetic and recreational value, promoting health and well-being and supporting green infrastructure. Water managed on the surface, rather than underground, can help to reduce summer temperatures, provide habitat for flora and fauna, act as a resource for local environmental education programmes and working groups and directly influence the sense of community and prosperity of an area. SuDS can provide opportunities for water to be visible and audible as it travels through the landscape – the places where water flows, stills, trickles or splashes are often where it is experienced and valued the most.

BOX 5.1 Amenity, place-making and liveability

Amenity may be defined as "a useful or pleasant facility or service", which includes the tangible (something that can be measured in terms of use), and the less tangible (something that can be experienced as pleasure or aesthetic appreciation).

This definition is particularly relevant for describing the multi-functional opportunities associated with SuDS designs, and it provides a link to the concept of **place-making**, now commonly used in describing the quality of a space in urban design.

Amenity also covers **liveability**, which is associated with factors that improve the quality of life for inhabitants. Liveability encompasses the well-being of a community and of individuals and comprises the many characteristics that make a location a place where people want to live and work.

There are many amenity benefits that are intrinsic to SuDS – good SuDS design often provides amenity benefits while delivering water quantity, water quality and biodiversity benefits.

Where the concept of "creating and sustaining better places for people" is embedded in the design process, these benefits can be maximised. **Table 5.1** provides a summary of how SuDS can add amenity value. Further information on amenity benefits of SuDS can be found in Digman *et al* (2015).

TABLE 5.1 Types of amenity benefits delivered by SuDS

Amenity category	Examples
Air quality improvements	SuDS using blue and green areas, including grass and trees, provide significant air quality improvements by, for example, trees "scrubbing" fine particulates from urban streets.
Air and building temperature regulation	Green and blue infrastructure buffers and moderates extreme temperatures, which will become increasingly important in future, as the climate changes and cities get hotter.
Biodiversity and ecology	Green and blue SuDS help to support flora and fauna for the benefit of communities, and it is here that SuDS amenity and biodiversity value come together (**Chapter 6**).
Carbon emission reduction and sequestration	Plants and soils take in and store CO_2 and other greenhouse gases, so where SuDS use plants this potential can be exploited. SuDS tend to require less energy use in all stages of the supply chain and life cycle than conventional drainage and, by harvesting water at source, this also saves energy.
Community cohesion and crime reduction	SuDS can help bring communities together. By increasing opportunities for human interaction and creating more enjoyable environments, people are more likely to feel they belong to the community and take a greater pride in their neighbourhood. This is especially the case if the community has been involved in the SuDS design process and residents have ownership of the ongoing maintenance (even if only in part).
Economic growth and inward investment	Attractive places (particularly where water is a feature of the design) tend to encourage and support inward investment. Productivity tends to be enhanced in attractive environments, such as business parks with green spaces. Green and blue SuDS have been shown to add value to land and property nearby. The SuDS in themselves may provide interest for tourists especially where they are a novelty. SuDS also contribute to the creation of attractive places that appeal to tourists.
Education	By using green and blue spaces as part of the management of the water cycle this provides many opportunities to support education both formally in schools and in communities as a whole through environmental groups.
Health and well-being	Green and blue infrastructure can play an important role in maintaining mental and physical health by providing places for recreation and relaxation (see *Recreation*).
Noise reduction	SuDS and associated trees and grassed areas can provide noise-absorbent barriers and surfaces. Green roofs provide sound insulation for buildings.
Security of water supply	Direct collection of rainwater to use for domestic and other purposes saves water, and potentially provides essential irrigation resources and long-term viability for amenity trees, vegetation and crops.
Recreation	SuDS can deliver a wide range of green and blue spaces that can be used for walking, cycling, informal play, organised sports and games etc (see *Health and well-being*).

Where SuDS are part of the wider "green" landscape, this tends to bring the widest range of benefits to people. The importance of green space (including spaces with water, sometimes referred to as blue space) to the quality of urban life is well recognised. For example, it plays an important role in tackling a range of health and social problems (Bird, 2007). Residents are more likely to reach recommended daily walking levels when they live near safe, attractive green spaces (Bird, 2004). Research studies have shown that patients in hospital rooms with views of trees and plants made fewer requests for pain medication and experienced a speedier recovery following surgery, compared to patients with views of streets and buildings from their windows (Ulrich, 1984). Tree views have also been shown to improve office workers' job satisfaction (Trellis, 2013).

Amenity and biodiversity are often considered together, but they are each important in their own right, and the overlaps and linkages should be recognised by designers. Designing for biodiversity is discussed in **Chapter 6**. Creating and sustaining as many amenity and biodiversity benefits as possible should be considered alongside designing for water quantity and quality.

CASE STUDY 5.1 The Triangle, Swindon

Figure 5.1 The green

The Triangle is an award-winning development of 43 low-cost properties (2, 3 and 4 bedrooms) for social housing in Swindon. The design looked to conserve 50% of the area for contiguous open space as a multi-functional landscape. The integrated plan combined social requirements with water attenuation and storage, biodiversity and edible streets and gardens.

All roof water is harvested and stored in underground tanks located in two kitchen gardens, accessed by hand pumps to irrigate vegetables and fruits. Surface water is attenuated in porous paving on all car park spaces, and the home zone street water is conveyed by a wide dished granite sett channel that clearly shows water moving towards a bioswale on two sides of the central triangular green. The base of the swale is planted with white willows and damp meadow species for biodiversity, water treatment, air improvement, urban thermal regulation and aesthetic amenity, making reference to the landscape signature of this clay lowland. It is a place for playing in, with stepping and balancing logs and bridges, and it forms a barrier for cars that might be tempted to park on the green.

Water filtered by vegetation is conveyed to a geocellular storage tank under the green, and a hand pump linked to a rill carved in a tree trunk allows kids to play with water. Finally, any excess water from the storage tank can be stored in oversized storm drains under the road, a requirement of Thames Water.

Figure 5.2 Play pump (a) and hand pump (b) in the kitchen garden (b) (courtesy Studio Engleback)

5.2 AMENITY DESIGN CRITERIA

5.2.1 Summary

The amenity design criteria presented here should be applied to maximise the amenity value from a SuDS scheme for the development and for the local and wider community.

The extent to which each amenity design criterion can be addressed by the designer will depend on local requirements and site-specific characteristics. Amenity objectives for surface water management systems may be specified at a catchment or local level within local development documents, and these should be referenced and considered early in the SuDS design process.

To facilitate the design of high quality, high value and truly multi-functional urban space that delivers effective drainage and also derives benefit from the presence of water, SuDS design should be considered during all stages of planning and site design (**Chapter 7**). This level of integration and multi-functionality is likely to require interdisciplinary working, particularly between landscape architects and drainage engineers.

Indicators can be used to evaluate the extent to which the amenity design criteria are being delivered by a SuDS design. The amenity design criteria and example indicators are presented in **Table 5.2**. A regulatory, approving or adoption body may choose to develop alternative indicators considered more appropriate for meeting local requirements or strategies (such as those relating to green infrastructure).

The criteria and the methods by which these criteria can be implemented for a site are then discussed further in the following subsections. These design criteria should be considered alongside design criteria for water quantity, water quality and biodiversity (**Chapters 3, 4 and 6**).

TABLE 5.2 Amenity design criteria and example indicators

	Amenity design criteria	Example indicators
1	Maximise multi-functionality	The number, variety and quality of additional and multi-functional uses for SuDS, such as recreational areas, car parking or traffic management
2	Enhance visual character	The proportion of the drainage system that is designed to be visually attractive, adds visual value to the development, supports local heritage and landscape character and integrates appropriately with the surrounding area
3	Deliver safe surface water management systems	The consideration of public safety within the design of each SuDS component (related to the "use" of the system as an amenity feature)
4	Support development resilience/adaptability to future change	The proportion of the drainage system that is designed with an allowance for future climate change or development change The proportion of the drainage system that will contribute to the development's climate resilience, such as reducing the heating/cooling needs of buildings or through shade provision
5	Maximise legibility	The proportion of the system that is visible
6	Support community environmental learning	The extent of community awareness strategies, school involvement, community education strategies, visitor provision etc

5.2.2 Amenity criterion 1: Maximise multi-functionality

Multi-functional land use will always deliver development outcomes that are more cost-effective and viable. This becomes particularly important in dense urban areas and is discussed further in **Chapter 10**.

Designing SuDS so that the space in which they exist performs multiple functions becomes increasingly important as the density and proportional impermeability of development rises. Opportunities for the creation of SuDS can be found in even the smallest of spaces, and lack of space should not be a reason for not using SuDS.

SuDS components can have a wide range of uses in addition to their water quantity and water quality management functions, and designers should work with planners and landscape architects to maximise the landscape value. Examples of where land for SuDS can have an additional use are discussed below.

Recreation

SuDS can offer a wealth of opportunities within developments for both passive and active recreation for the local community.

Where possible, surface water management systems should be designed to help create relaxing, pleasurable, useable, useful and fun environments for local communities to enjoy. SuDS designs can create conditions where people can interact with and enjoy water in ways that are relaxing, entertaining, stimulating and refreshing as well as aesthetically pleasing (**Section 5.2.3**). Larger open water and wetland areas can provide a focus for footpaths and trails, providing attractive areas for walkers, cyclists and joggers, with access to the water at appropriate locations. Larger areas of permanent water in SuDS ponds can potentially provide opportunities for angling and wildlife observation.

Water and play go well together (see **Case study 5.2**). Most children (as well as some adults and pets) enjoy playing with water. While playing, children can also learn at the same time. Water areas for play include shallow pools, artificial channels and chutes (some of which will only be wet when it rains). A number of best practice guides are available for maximising the benefit value and opportunities from the use of SuDS for play, for example from Planet Earth Ltd (2010).

CASE STUDY 5.2 **Orange Park, London**

Figure 5.3 Orange Park, London (courtesy Planet Earth)

At Orange Park in the City of Westminster, London, the colourful ceramic decorated concrete channels branch outward and diversify, leading this way and that, between hills, under bridges and finally into reed beds. During rainfall, the runoff is captured and channelled, allowing children to chase, hop and splash in the water until it eventually reaches planting beds with integrated soakaways.

Using exceedance storage areas (ie surface water storage zones designed to manage large, rare rainfall events) for recreational purposes, such as sports pitches, can increase their economic viability. The likely inundation frequency of an area and the time taken for it to recover following a flood will tend to determine the suitability of its use for other functions. Where components of drainage systems lie beneath the ground, the land surface can often have a secondary use, provided that this does not pose a structural risk to the SuDS component. For example, subsurface attenuation storage systems can be sited below permeable surfaces used for recreation, local roads or car parking.

Traffic management

Surface water management components can often be integrated with road space, traffic management schemes and sustainable transport corridors (eg cycle routes) to manage day-to-day and/or exceedance flows while potentially aesthetically enhancing the urban environment. Where bioretention systems are integrated with traffic calming build-outs, for example, they can also assist in improving local environments and bringing enhanced economic development.

Figure 5.4 Examples of bioretention systems providing traffic calming measures, Llanelli (courtesy Dŵr Cymru Welsh Water)

Car parking and streetscapes

Where a car parking or pedestrian/cycle way surface is designed to be pervious, surface water can be stored and treated within the sub-base, before controlled discharge or infiltration into the ground.

Vegetated strips, swales, bioretention systems, tree pits and basins can be designed adjacent to car parks in required green space provision to treat and control runoff, while at the same time providing amenity value to car park users and adjacent pedestrian, commercial and residential zones. Rain gardens and bioretention areas can be integrated into a streetscape complementing or supporting the delivery of a wide range of street features, such as on-street parking, pedestrian crossing points and spaces for cycle hire and storage.

Figure 5.5 Rain garden, Ribblesdale Road, Nottingham (courtesy Environment Agency)

Figure 5.6 Community planting event for rain garden, Derbyshire Street, Bethnal Green, London (courtesy Greysmith Associates)

Figure 5.7 Greenwich University vegetable growing plot

Figure 5.8 Portland City Council edible garden (courtesy Heriot-Watt University)

Horticulture

Urban communities are also increasingly creating spaces for horticulture. SuDS can support the irrigation needs for such areas (see **Chapter 3** water quantity criterion 1) and can be integrated with new productive landscape spaces. These productive landscapes not only provide harvestable fruit and vegetables, but also support community cohesion, the aspirations of individuals and opportunities for employment and add to biodiversity.

5.2.3 Amenity criterion 2: Enhance visual character

Urban spaces should be designed to provide high quality, visually attractive and appealing places for residents, workers and visitors. Each surface conveyance and storage component within the SuDS Management Train can enhance the visual aesthetics of the development and contribute to building character (eg green roof) or to the setting for the buildings. SuDS can be designed to integrate with and improve the built form and surrounding urban landscape and contribute to new or support existing green space.

Landscape Institute and the Institute of Environmental Management and Assessment (2013) provides best practice guidance on assessing and enhancing the visual amenity of land. Many planning applications require some form of visual assessment. For larger schemes, the assessment is part of the statutory procedures in the Environmental Impact Assessment (EIA). Landscape and visual effects should be assessed separately despite being linked. The former is considered as an effect on the environment, while the latter is considered in terms of the effects on people.

By enhancing visual character and increasing the attractiveness of individual buildings, locations and areas, SuDS can help contribute to a number of amenity benefits, including enhanced economic investment within the local area, increased employment productivity due to the quality of the working environment, enhanced property and land values and increased tourism.

Figure 5.9 Canalside living, Redhill, Surrey (courtesy Studio Engleback)

Not all of these benefits are exclusively because of SuDS, and many would come about anyway if green areas were used or open water features added to a landscape. It is important that visual benefits are not attributed incorrectly to SuDS unless greening of an area would not have happened without SuDS being installed (**Chapter 35**).

The visual aesthetic value should be considered at elevation as well as at ground level. Well designed and integrated SuDS components can contribute to urban art, townscape character and the distinctiveness of a location, attracting tourists and enhancing the quality of life of those who use the area. The ways in which runoff can be managed, to provide attractive and interesting visual structures on individual buildings such as roofs, walls, spouts, cascades, rain slides, rain chains etc, is only limited by the designer's imagination and creativity and the need to ensure a safe environment.

The design of a surface SuDS component should enhance the experience of movement or tranquillity with opportunities taken to stimulate the senses, not only visually but also through sound and touch. Each component should be attractive, and wherever possible the value of water within each part of the system should be considered and promoted. Managing noise, by excluding unwanted sounds and replacing them with the tranquil sound of moving water, brings the visual and the auditory experience together in helping create enjoyable, tranquil and pleasant places.

As water flows from one component to the next, the structures that control movement should blend with the landscape and take into account the use and place of SuDS within the surrounding area. At the same time they should be visually neutral or positively interesting as part of the SuDS Management Train (**Chapter 28**).

Figure 5.10 SuDS and play (courtesy DSA Environment and Design)

5.2.4 Amenity criterion 3: Deliver safe surface water management systems

SuDS are no more hazardous than natural ponds and wetlands, puddles and surface runoff flows on roads, or in streams and rivers. Guidance on health and safety is provided in **Chapter 36**, which includes health and safety risk assessment processes and design approaches to mitigate any potential risks associated with the system. This criterion concerns the consideration of public safety related to the "use" of the system as an amenity feature or resource.

Therapy garden

Rain garden

Figure 5.11 Alcester Primary Care Centre (courtesy DSA Environment and Design)

The designer should mitigate any risks associated with the system, so that the interaction is sufficiently safe for potential users.

Edges where water meets dry land need special care with each design element considered for safety and maximum benefit to the user. Design guidance on edge designs, safe slopes, barriers etc is provided within individual SuDS component chapters (**Chapters 11–23**) and summarised in **Chapter 36**.

Where rainwater or runoff is likely to be contaminated and unsafe for human exposure, it should be kept within systems that do not encourage or facilitate potential contact or should be treated before use.

Provided that runoff is not contaminated, it can be used as a children's play resource and to irrigate areas that are used for recreation. An upstream treatment train and appropriate risk assessment will determine at what point the water is appropriate for use as a play or amenity resource (**Chapter 36**). The design of amenity features should ensure that they do not give the impression of the water being potable, for example, pumps, fountains, or jets are usually fed with mains water and where these may be perceived as using water that is safe to drink, or where there is significant spray or aerosols, these should not be supplied with untreated water.

Where SuDS are part of play and recreational facilities, although there are some fears about safety of play with water, the HSE (2012) contends that there is a need to take a balanced approach and for play providers to focus the provision of play facilities on controlling the real risks, while at the same time "securing or increasing the benefits" that these facilities can provide.

Figure 5.12 Planted canal, Stamford (courtesy Roger Nowell)

Figure 5.13 Inlet, Heriot Watt Science Park

5.2.5 Amenity criterion 4: Support development resilience/adaptability to future change

The requirement for adaptability over the life of the SuDS should be considered as part of the design process. Urban environments are constantly changing and never complete (Digman *et al*, 2012). Changes can come about due to climate change and urban creep (**Section 3.2.7**), but change may also come directly from local policy initiatives driven by, for example, local community demands, and these changes may need to be accommodated by adapting drainage systems.

The future resilience of urban areas to climate change and societal stresses that are largely unpredictable depends on how readily urban systems can be adapted. Surface water management systems that integrate surface water features can be more readily modified than underground systems.

SuDS can also help developments be more resilient to future climate change. The potential use of SuDS to deliver key sustainability and climate resilience planning objectives for the development should be considered early in the design process, to maximise benefits and reduce costs.

Through harvesting and using rainwater, SuDS can contribute to water security of individuals and communities where water scarcity is likely to increase. Green and blue spaces provide cooling via the return of moisture to the air through evaporation and evapotranspiration from vegetated and water features, which can help to reduce temperature increases in urban areas (urban heat island effect). Trees can also provide direct cooling by providing shade for buildings and outside amenity space. Green roofs and vegetative surfaces reflect more sunlight and absorb less heat, thereby keeping buildings cooler in summer and, conversely, providing building insulation during winter months, which in turn can reduce energy usage.

5.2.6 Amenity criterion 5: Maximise legibility

Where possible, it is important to bring the process of collection, conveyance, storage and treatment into the open, making the system and its function more obvious to local communities, visitors and those inspecting and maintaining the system. Many SuDS are visible, that is "on the surface" with a minimal below-ground system (as advocated in **Chapters 3 and 4**). Even when they are located on private land, they will often be within the public realm. This "legibility" encourages a connection between the SuDS scheme, water, the community and the place in which it sits. When it is obvious how a surface water management system works, local communities are more likely to act to protect its long-term functionality, including setting up voluntary working groups or taking individual actions to maintain and enrich the SuDS (see also **Section 5.2.7**).

Figure 5.14 Signage and todder-proof fencing at a supermarket site (courtesy ACO Limited)

Where SuDS components are on the surface, blockages and other performance risks are also easy to see and rectify. For example, it is easy to see when there is contamination from pollutants, especially from misconnected foul drainage, as there will be evidence, for example, of faecal material and associated solids from toilets, food from kitchens and discoloured grey water from washing machines and human use.

Inlets, outlets and flow control structures in particular are critical to the effectiveness of SuDS. Their location should be obvious and their functionality easily understood by maintenance contractors (**Chapter 28**).

Figure 5.15 Pond dipping (courtesy Illman Young)

Figure 5.16 Shared learning at Stebonheath (courtesy Dŵr Cymru Welsh Water)

5.2.7 Amenity criterion 6: Support community environmental learning

Opportunities should be sought to use SuDS as a resource for community environmental learning, as this will help to ensure that the benefits to the community of the SuDS are maximised. This is complementary to (but separate from) community engagement. For the purposes of this manual, community engagement refers to the planned process of working with specific groups of people to identify opportunities and address issues affecting them or their community, such as how the proposed scheme will look, function and be maintained (**Chapter 34**). Community environmental learning can come about through community engagement or through the public's interaction with the services and amenities provided by SuDS. This interaction helps to foster an appreciation of natural drainage systems and the links between rainfall, water supply, runoff, flooding and pollution.

Rainfall and runoff can provide exciting educational and playground resources. Vegetated conveyance and/or surface pond storage systems can be designed to promote education, play and amenity value via, for example, swale mazes and pond dipping.

Community activities, related to local SuDS, can help to develop community cohesion and engender a sense of local identity and pride where the SuDS contribute to enhancement of the environment, especially where SuDS have been retrofitted to manage, say, a local flooding problem. Such activities also help to encourage communities and individual property and land owners not only in looking after their own SuDS, but potentially also the wider environment.

Raising awareness, appreciation, understanding and capacity of communities and individuals to interact with SuDS can be supported through:

- direct engagement in their planning, delivery, commissioning and operation (**Chapter 34**)
- the provision of information at appropriate points in the system (eg via interpretation boards, special events and direct contact)
- promoting wider local interest in, and interaction with, SuDS via school visits, educational presentations and inclusion in national curriculum activities
- promoting recreational and other uses of the system by both children and adults (**Section 5.2.2**).

By involving the local community and individuals in the implementation and/or maintenance of SuDS (such as planting days, see **Figure 5.18**), this can promote:

- understanding of the functionality and importance of the natural environment and the place of surface water management in mitigating human impacts on the environment
- commitment towards contributing to the management of the SuDS, which also engenders positive attitudes towards the system, enhanced enjoyment from it and social cohesion and support mechanisms
- understanding of the importance of, and arrangements for, health and safety risk management for the site in relation to surface water
- use of the system as an educational resource for local children and adults, with respect to safe play near water, ecology and an understanding of the movement of rainwater through the urban and natural environment.

Figure 5.17 SuDS outreach project, Portland (courtesy Portland Bureau of Environmental Services)

Figure 5.18 Planting at Coppetts Wood Primary School (courtesy WWT)

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Image courtesy Grant Associates

6 DESIGNING FOR BIODIVERSITY

Contents

Chapter 06

Designing for biodiversity

This chapter explains the objective of designing for biodiversity and the design criteria that should be followed to deliver this objective.

- *This chapter should be read alongside Chapters 3–5 to understand how the different SuDS design criteria relate to each other, and Chapter 7 to understand when and how to apply these criteria.*
- *Guidance on planting can be found in Chapter 29.*

6.1 BIODIVERSITY DESIGN OBJECTIVE

Create and sustain better places for nature

Policy-makers now recognise the important contribution that designing for biodiversity can make to ecosystem services (**Box 6.1**) and improved community "living" space. "Connecting people with nature" is a UK government objective (Defra, 2011), which SuDS can help deliver.

The benefits of creating new habitats and rehabilitating or enhancing existing habitats through SuDS design go far beyond the contribution that planting makes to the functionality and performance of the drainage system (**Chapters 3 and 4**). Landscape features that support diverse habitats and associated ecosystems provide a healthy and stimulating environment that can add significant value to urban living (**Chapter 5**). The water within a SuDS component or scheme is an essential resource for the growth and development of plants and animals. Biodiversity value can be delivered by even very small, isolated schemes, but the greatest value is achieved where SuDS are planned as part of wider green landscapes, as they can then help provide important habitat and wildlife connectivity. With good design, SuDS can provide shelter, food and foraging and breeding opportunities for a variety of wildlife species including plants, amphibians, invertebrates, birds, bats and other mammals.

Designing SuDS space for biodiversity requires drainage designers, urban and landscape designers, planners and ecologists to work together. For many sites, a qualified ecologist is likely to be required for the project. However, all members of the SuDS design team should understand the principles behind designing for biodiversity and should recognise the benefits that result.

Amenity and biodiversity are often considered together, but they are each important in their own right and, although the overlaps and linkages should be recognised by designers, they are dealt with in separate chapters of this manual. Designing for amenity is discussed in **Chapter 5**. Creating and sustaining as many amenity and biodiversity benefits as possible should be considered alongside designing for water quantity and quality.

The design of habitats in SuDS needs consideration and integration at all stages in the planning process, from master planning to detailed design (**Chapter 7**), taking into consideration broader green infrastructure objectives where applicable, if it is to deliver maximum biodiversity value. There are well-established techniques for creating habitats in new landscapes serving developments, and these are described in general habitat creation guidance in Dale *et al* (2011) and for previously developed land in Jackson *et al* (2011). The formal process of integrating biodiversity considerations and delivery into all stages of the planning, design and development process is set out in BS 42020:2013.

BOX 6.1 **Useful definitions**

Biodiversity encompasses the number, abundance and distribution of all species of life on earth. It includes the diversity of individual species, the genetic diversity within species and the range of habitats that support them. Biodiversity also includes humans and our interactions with the environment (Dale *et al*, 2011). Locally, biodiversity reflects the character of the plants and wildlife that share the space in which humans live, work and play.

Ecology is the study of plants and animals and the relationships between them and their physical environment.

An ecosystem is a biological community and its physical environment (Dale *et al*, 2011). Reconciliation ecology is the branch of ecology that studies ways to encourage biodiversity in human-dominated (eg urban) ecosystems.

Ecosystem services are the benefits provided by ecosystems that contribute to making human life both possible and worth living. Examples of ecosystem services include products such as food and water, regulation of floods, soil erosion and disease outbreaks, and non-material benefits such as recreational and spiritual benefits in natural areas (Albon *et al*, 2011).

Natural capital refers to the elements of nature that produce value to people, such as the stock of forests, water, land, minerals and oceans. These provide benefits such as food, clean air, wildlife, energy, wood, recreation and protection from hazards (Natural Capital Committee: **http://tinyurl.com/ow3qf76**).

Green infrastructure is a term to describe strategically planned and interconnected networks of natural and manmade green spaces (including blue space) or corridors that deliver a function for the local community.

TABLE 6.1 **Biodiversity design criteria and example indicators**

Biodiversity design criteria	Example indicator
1 Support and protect natural local habitat and species	The extent, quality and significance of local habitats supported or enhanced by the SuDS design
2 Contribute to the delivery of local biodiversity objectives	The habitats delivered by the SuDS design that meet objectives set out in local biodiversity frameworks/strategies
3 Contribute to habitat connectivity	The extent to which the SuDS scheme is integrated with wider green infrastructure strategies, or is helping to support or connect habitats.
4 Create diverse, self-sustaining and resilient ecosystems	The range and diversity of habitat types delivered or supported by the SuDS design, and the likely resilience of these habitats and the ecosystems they support to potential future change

CASE STUDY 6.1 **Manor Park, Sheffield**

Figure 6.1 View over the park showing the SuDS working as predicted following heavy rain in 2007 (courtesy Sheffield City Council)

Figure 6.2 Conveyance component (courtesy Sheffield City Council)

Manor Park in Sheffield has a series of ponds and basins that were installed to attenuate and treat road runoff from a new housing estate on brownfield land. The SuDS scheme improves water quality sufficiently to provide valuable habitat and a safe and visually pleasing public open space.

6.2 BIODIVERSITY DESIGN CRITERIA

The biodiversity design criteria presented here should be applied to maximise the biodiversity value from a SuDS scheme for the development and for the local and wider environment.

The extent to which each biodiversity design criterion can be addressed by the designer will depend on local requirements and site-specific characteristics. Biodiversity objectives for surface water management systems may be specified at a catchment or local level within local development documents, eg green infrastructure strategies, and these should be referenced and considered early in the SuDS design process. Delivery of local biodiversity objectives (**Section 6.2.2**) in particular should be a key consideration in the design.

Amenity design criteria are described in **Chapter 5**. Both amenity and biodiversity design criteria should be considered together and at an early stage and fully integrated into the design process in order to maximise the opportunities that can be achieved by the scheme at no or minimal extra cost.

Indicators can be used to evaluate the extent to which the biodiversity design criteria are being delivered by a SuDS design. The biodiversity design criteria and example indicators are presented in **Table 6.1**. Environmental regulators, local authorities, approval or adoption bodies may choose to develop alternative indicators considered more appropriate for meeting local requirements.

The criteria and the methods by which they can be implemented for a site are then discussed further in the following subsections.

6.2.1 Support and protect natural local habitats and species

The habitats and species within any new SuDS scheme should aim (where appropriate) to be similar to, linked with and/or supportive of the natural and semi-natural local habitat and associated species.

The designer needs to understand the habitat types in the area in order to determine the most appropriate habitats for the site, that is habitats that will work with and enhance any existing habitats and complement the use and future objectives of the site development.

Characterising the main ecological communities that might naturally thrive in the locality is an effective starting point to define how best to conserve or create supportive habitats through the use of SuDS. Characterisation methods are described in **Chapter 7**.

The most appropriate ecological design for the site will depend on:

- habitats and biodiversity that thrive naturally in the locality
- wider regional habitats and biodiversity for which the provision of connectivity through the implementation of the SuDS would be of value
- whether there are significant natural local habitats such as wetlands that have been lost or fragmented over time, and whether it is appropriate for these to be recreated or reconnected as part of the development drainage design
- the characteristics of the site that will influence the suitability of vegetation, habitat types and the species they support, such as aspect, topography, soils, local climatic and hydrological variables
- the requirements of the new site and local community, for example proposed and/or existing use, amenity provision, development landscape character and style.

CASE STUDY 6.2 **Green roof at Horniman Museum, London**

Figure 6.3 Green roof at Horniman Museum, London (courtesy Gary Grant)

A ten-year survey found that the green roof at Horniman Museum developed into species-rich grassland supporting a number of plants notable to London. This roof created the opportunity for these species to thrive and be enjoyed in a protected environment. The south-facing section is sandy and dry, dominated by grasses. The roof supports abundant meadow wildflowers and taller meadow grasses on the wetter north-facing section, and gaps in the turf have allowed further plant species and mosses to flourish.

6.2.2 Contribute to the delivery of local biodiversity objectives

SuDS design should prioritise habitats and species objectives that contribute to local, regional and national biodiversity targets (Four Countries' Biodiversity Group, 2012).

Across Europe it is increasingly being recognised that there is a need to protect threatened species and habitats and promote biodiversity, including restoration of habitats (wildflower grasses, wetlands etc). SuDS can often be designed to benefit priority habitats (defined as those most threatened and requiring conservation action) and help deliver strategic objectives set out in national and local biodiversity strategies, frameworks and action plans.

National strategies recognise the importance of local level initiatives in creating and sustaining biodiversity, and the funding provided for biodiversity schemes can often help to co-fund and deliver better surface water management schemes (where these are supportive of biodiversity). When designing SuDS, co-operation with those delivering local biodiversity strategies (including Local Nature Partnerships) will ease approvals and also provide new opportunities to add value.

Effective and sympathetic Maintenance Plans for SuDS that take account of the wildlife supported by the habitat provided are essential, particularly where protected species such as bats, birds in the breeding season, water voles and great crested newts and other important invertebrates and mammals are likely to be present. It is important to seek expert advice from ecologists to produce a plan that maintains a favourable habitat for wildlife and, where they exist, protects sensitive and legally protected species. If protected species are recorded or designed for at the proposed site, details of the legal requirements associated with the species should be sought from relevant government agency guidance.

General guidance on Maintenance Plans is set out in **Chapter 32** and maintenance requirements for specific SuDS components are provided in the individual technical component chapters (**Chapters 11–23**).

6.2.3 Contribute to habitat connectivity

The habitats within any new SuDS scheme should, where possible, link with other local and/or regional habitats to help build and enhance habitat connectivity within neighbourhoods and between rural/suburban areas and towns/cities. This will help mitigate the problems associated with habitat loss and fragmentation within urban areas. The SuDS design should consider existing or future planned habitat corridors and networks, and evaluate how the SuDS on the site can best support or contribute to these wider objectives by providing linking habitats or stepping stones – allowing wildlife to move from and to rural areas, as well as being urban habitats in their own right.

Green infrastructure is vital to the creation and maintenance of ecological function in urban space providing habitats for fauna in their own right, pathways for migrating animals and natural plant colonisation, as well as safe passage for surface water runoff that exceeds the drainage system capacity.

Healthy ecologically functioning habitats can be promoted by linking proposed development sites to adjacent areas with established or latent biodiversity potential and ideally with a well-developed assemblage of plants and animals that can easily colonise the new spaces created by the SuDS design. Unless there is significant existing contamination, all sites are likely to become colonised by plants, followed by animal species. Best practice SuDS design for biodiversity can ensure that this colonisation is high quality, high value and as rapid and robust as possible.

Examples of new developments where the design of the site is laid out around green corridors that convey surface water are shown in **Figure 6.4**.

CASE STUDY 6.3 Gosforth Valley wetlands, Dronfield

Tree planting

The balancing pond in winter

Dunnock (Prunella modularis)

Putting up bird boxes

Figure 6.4 The wetlands and example of activities by the volunteers (courtesy Norman Crowson)

The Gosforth Valley wetland area is owned and managed by Yorkshire Water with the support of Dronfield Town Council and the Lea Brook Valley Volunteers.

The pond and wetland area stores and treats excess water collected from the surrounding area (via public surface water sewers and highway drains) during and after periods of heavy rainfall. The water level in the pond is controlled by a balancing dam that gradually releases water into the Lea Brook to prevent flooding of areas further downstream.

The wetland area includes many native trees and plants which help to improve the amenity and biodiversity of the site. It is very important for the conservation of wildlife within Dronfield and North East Derbyshire. The habitat has been developed to support wetland bird species such as shoveller (*Anas clypeata*), grey heron (*Ardea cinerea*), and snipe (*Gallinago gallinago*), invertebrates such as the common darter (dragonfly) (*Sympetrum striolatum*), water boatman (*Notonecta glauca*) and water flea (*Bosmina longirostris*); amphibians such as the common frog (*Rana temporaria*) and common toad (*Bufo bufo*) and mammals such as the European water vole (*Arvicola amphibius*).

The site forms part of the larger Lea Brook Valley, which is a green corridor into Dronfield town centre. The Lea Brook Valley Project is aimed at enhancing the beauty, amenities and wildlife habitat of the valley, for the benefit of the residents and wildlife. Run by volunteers, it works with local conservation groups, the local parish council, Yorkshire Water and others, carrying out many activities, such as conserving the local ancient hedgerow, creating a nature trail, providing interpretation boards, planting trees, setting up bird boxes and litter picking.

This project is one of several conservation projects in the area. Together these projects provide a ten-mile wildlife corridor between Dronfield and Chesterfield.

Deanshanger, Buckinghamshire (courtesy Ilman Young)

Upton, Northamptonshire (courtesy Peterborough City Council)

Figure 6.5 Green corridors

6.2.4 Create diverse, self-sustaining and resilient ecosystems

SuDS schemes should aim to have a range of habitat types, as this will encourage biodiversity and result in self-sustaining and resilient ecosystems.

Designing for ecological resilience is about ensuring that habitats, and the species they support, can evolve as naturally as possible and continue to meet the objectives of the drainage system. Most species require a range of environmental features within a site or a wider landscape to complete their life cycle. Many of these elements, such as small patches of bare ground, tall flower-rich vegetation or scattered trees and scrub, are often absent from the English landscape, and even from our most important wildlife sites, which has contributed to species decline. SuDS components are likely to have greater species diversity and resilient ecosystems if existing habitats are within dispersal distance for plants, invertebrates and amphibians, allowing natural ecological colonisation and future re-colonisation should damage occur due to pollution etc.

Climate change will affect the distribution of wildlife, habitats and the health of ecosystems which, in turn, will have an impact on human well-being. A well-designed and managed surface water management system will be intrinsically more resilient to changes in climate (**Chapters 3–5**). Equally, SuDS that have structural diversity as well as biodiversity will promote ecological resilience, with different groups of plants and animals emerging over time. This should not only be taken into consideration for the site itself, but also for the wider ecosystem. For example, where SuDS help reduce habitat fragmentation (**Section 6.2.3**), this will also help the movement of species as they track suitable "climate space" (ie the geographical range of suitable climate for a species).

Structural diversity can be delivered through the use of a variety of SuDS components as part of the overall SuDS scheme. This can be enhanced through the use of subtle changes in ground profile (vertically and horizontally). When combined with a range of vegetation types (such as wildflowers and other nectar-rich plants, grasses, drought-tolerant species, marginal-aquatics and wet grasslands, open water, trees and shrubs – see **Chapter 29**) it is possible to deliver a diverse range of habitats for little or no extra cost beyond the requirements for delivering water quantity and quality.

Further guidance on how to maximise biodiversity value within a SuDS design is provided in **Section 6.3**.

CASE STUDY 6.4

Watercolour, Redhill, Surrey

Figure 6.6 Watercolour, Redhill (courtesy Studio Engleback)

The Watercolour development of 523 homes is located on a former sand washing plant. An industrial outwash lagoon and settlement lagoon have been restored on the site, and the Gatton Brook, which runs around the edge of the site, has been re-established, having been previously culverted under industrial buildings. The lagoons are linked together and fed by a linear green space that the runs through the middle of the development. These in turn then discharge to the Redhill Brook. A large reed bed is provided in line with local habitat action plans. These ecological corridors link the town to the nearby country park and provide a valuable wildlife resource (including habitat for a large number of newts), while also attenuating and treating surface water runoff. The site includes 3 ha of public open space with a further 10 ha (including the two lagoons) of nature reserve managed by the Surrey Wildlife Trust.

6.3 SUDS DESIGN CHARACTERISTICS TO SUPPORT BIODIVERSITY

This section presents a summary of the design characteristics that will contribute to the delivery of biodiversity value for a SuDS scheme. Further information can be found in Graham *et al* (2012). The focus here is on wet and planted features. However, there will be biodiversity value associated with other surface types, eg gravel, aggregate, grit and mulch, particularly for insects and spiders.

6.3.1 Structural variability

A SuDS scheme should include both horizontal and vertical structural variability. This can be achieved in the following ways:

- Use a variety of SuDS components and combine these with the natural longitudinal gradients required for conveying water through the landscape.
- Use excavated topsoil and subsoil from the site by forming banks, mounds and terraces to provide mosaics of permanently wet, temporarily wet and dry features that will aid the development of a wide range of habitats. For example, "hummocky margins" in shallow water can mimic natural wetland habitats.
- When designing pond and wetland features, use the sequence of riparian dry-level bench (required for safety and maintenance access), gentle slopes, wet shallow safety bench, shallow and possibly deeper water zones to help to deliver a physically and ecologically diverse landscape.
- Use variations in topography to protect ecologically valuable features from insensitive mowing regimes by providing a physical constraint.
- Avoid smooth finished surfaces commonly seen in ditch and drain edges, retaining walls etc, as these "tidy" edges do not encourage habitat development.

Swale

Pond

Figure 6.7 Pond and grassland habitat mosaic, Moreton-In-Marsh Community Hospital, Gloucestershire (courtesy Illman Young)

6.3.2 Biodiverse planting

A SuDS scheme should include a diverse range of planting. Biodiversity can be enhanced in the following ways:

- Use planting of known wildlife value, wherever possible, that is appropriate to the location.
- Never introduce invasive species.
- Wherever possible, maximise the use of plants that are native and of local provenance, appropriate to the region and suited to local soils and hydrology. Non-native plants can be considered in formal situations, such as rain gardens adjacent to habitation.

- Where non-native plants are used, only use plants of high nectar and aesthetic value. They should not be invasive, or liable to spread into and impact on important sensitive habitats, or dominate the planting scheme in which they have been included.
- Choose species which, when planted together, maximise all-year-round leaf coverage, flowering and fruiting periods to provide food and shelter for invertebrates and birds.
- Allow natural colonisation by plants and animals of desired/intended species to take place during the SuDS establishment process.
- Provide a variety of heights of grasses throughout the site, as wildlife will utilise grasses of different heights in a variety of ways (**Box 6.2**).
- Encourage flowers into grasslands (by natural colonisation, seeding or planting), as these provide nectar for a variety of insects.
- Consider planting gravel surfaces with nectar-rich plants, tolerant of drought, foot and vehicle damage, for example chamomile and thyme.
- Where SuDS components require 100% vegetation cover before the system is commissioned (eg swales) which means that turfing is essential, use flower-rich turf or add wildflower plugs to standard turf.
- Where necessary, use turfs that can withstand high flows and extended periods of waterlogging.
- Include trees, scrub and wet woodland features. These can increase habitats for amphibians and invertebrates and provide some valuable shaded areas. Appropriate management of these areas will be required to ensure that the intended biodiversity is retained.
- Maximise opportunities for providing or retaining dead wood in dry or wet areas. Dead and decaying wood is valuable for mosses, lichen and fungi. It is also particularly important for invertebrates, as many species rely on it for completing all or part of their life cycles. Standing deadwood can also provide cavities for birds and bats for breeding and roosting.

See **Chapter 29** for further guidance on planting.

Box 6.2 The importance of grasslands

Grasslands are particularly important for wildlife. For example:

- Birds and mammals will forage for seeds and insects in different lengths of grass.
- Taller grasses will help retain humidity and soil moisture, which will in turn benefit soil invertebrates.
- Longer swards provide somewhere for the eggs, pupae or larvae of some insects to over-winter in the grass thatch. They will also be used by bumble bees for nesting.
- Beneath trees and adjacent to shrubs, invertebrates that feed in the trees and bushes can pupate in the grass to complete their life cycle.
- Flying insects may shelter in longer grass during rain or sudden changes in temperature and roost overnight.
- Reptiles and amphibians will search for insects in longer grass and use it as cover when moving between sites.

6.3.3 Biodiverse water features

A SuDS scheme should include biodiverse and resilient water features. These can be achieved in the following ways:

- Manage the risk of toxic, pathogenic or otherwise harmful substances and silts that can smother wildlife being discharged into the water feature (**Chapter 4**).
- Where possible, retain existing habitats and incorporate these into the landscape design, and locate SuDS near to less intensively managed landscapes that are near to (but not connected to) natural ponds and wetlands.

- Maximise shallow and occasionally inundated areas of emergent pond vegetation, as these habitats are more resistant to pollution than submerged areas, and they have high ecological value.
- Where possible, design the system so that some zones are not exposed to every runoff event and/or are fed from a separate runoff source that is as clean as possible, such as roof water.
- Where appropriate, create shallow grassy wet areas along dry swales and basins, particularly towards their downstream ends, where the water should be cleanest. These can be as small as 1–2 m wide and 100 mm deep. Shallow scrapes, linked with sinuous surface channels of varying width will increase opportunities for wildlife and slow water flows.

Figure 6.8 Infiltration basin with wildflower turf and grass seeding, Victoria Park Health Centre, Leicester (courtesy DSA Environment and Design)

Figure 6.9 Wetland with marginal aquatics, grasses, sedges, rushes and wildflower grass seed mix, Kington, Herefordshire (courtesy DSA Environment and Design)

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Statutes

BS 42020:2013 *Biodiversity. Code of practice for planning and development*

Everyone with an interest in SuDS

Those responsible for policy or decision making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS Manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

C

Audience:
Those responsible for policy or decision making
Those responsible for delivering and managing a SuDS scheme

Applying the approach

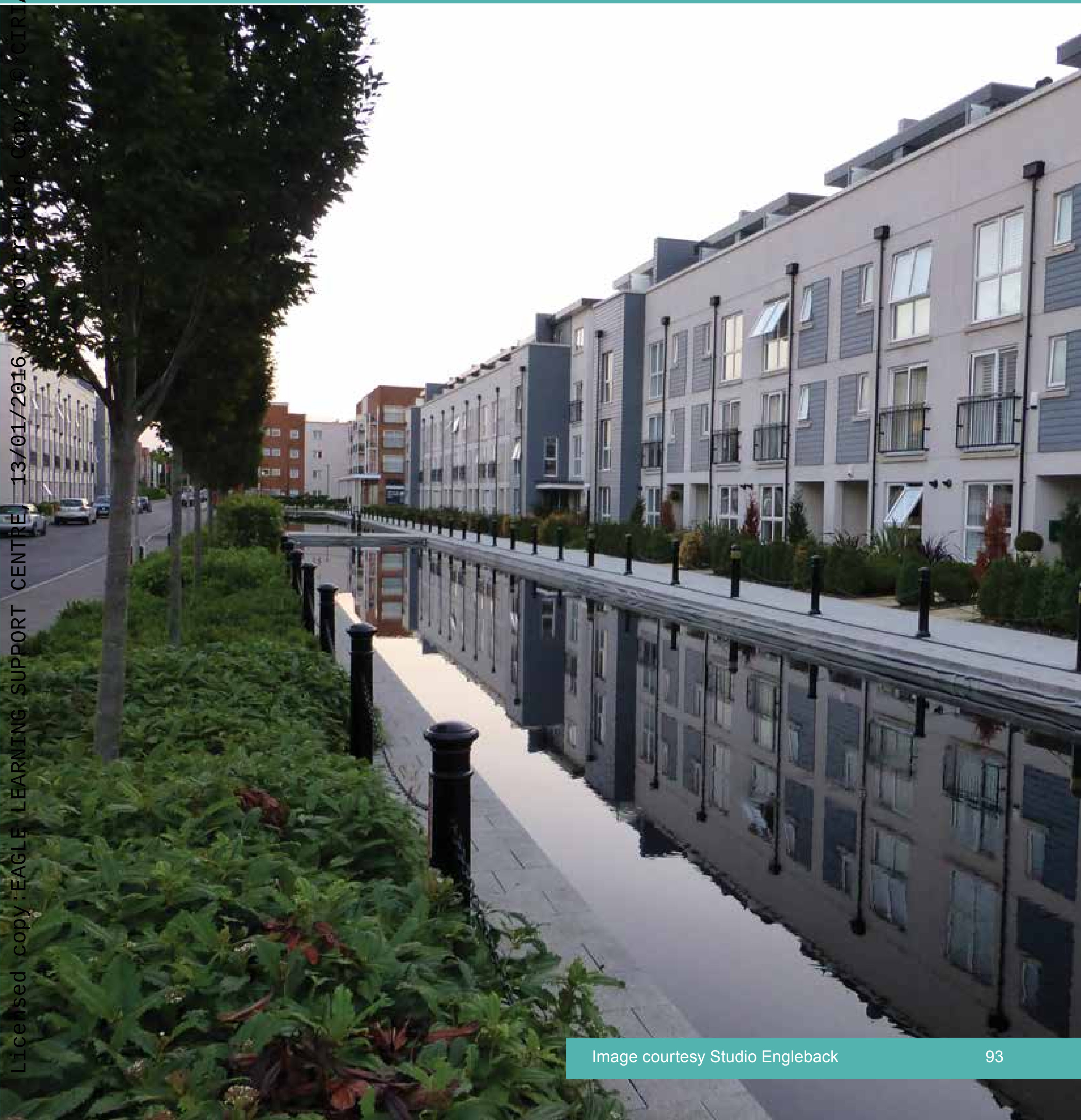

Image courtesy Studio Engleback

Image courtesy Leicester County Council

7 THE SUDS DESIGN PROCESS

Contents

Chapter 07

The SuDS design process

This chapter sets out the stages of the SuDS design process, from early consideration of the strategic objectives for a development through to detailed design. The process is relevant for new development, redevelopment, infill or retrofit SuDS sites, with the level of detail and relevance of certain stages determined by the development type, size and complexity. A step-by-step guide to carrying out each of the design stages is provided, linking design criteria and standards to guidance on design methods.

- *The SuDS design criteria and standards referred to in this chapter are presented in Chapters 3–6.*
- *Guidance on design methods is provided in Chapters 24–26.*
- *Appendix C presents the design phases for a hypothetical SuDS scheme, demonstrating the design process (as described in this chapter) and the detailed hydraulic and treatment design of individual components.*

7.1 INTRODUCTION

The SuDS design process should begin as early as possible in the feasibility stages of a development project and, wherever possible, should be a consideration before land purchase. Where SuDS form part of the initial development vision, character and layout, they can provide a range of creative opportunities – using water to shape and enhance development space and maximise the functionality, value and desirability of the development.

The SuDS design process broadly follows four stages, as shown in **Figure 7.1**, and details of the tasks involved are set out in **Sections 7.5 to 7.8**. Further detail on the application of each of these stages can be found in AECOM (2013).

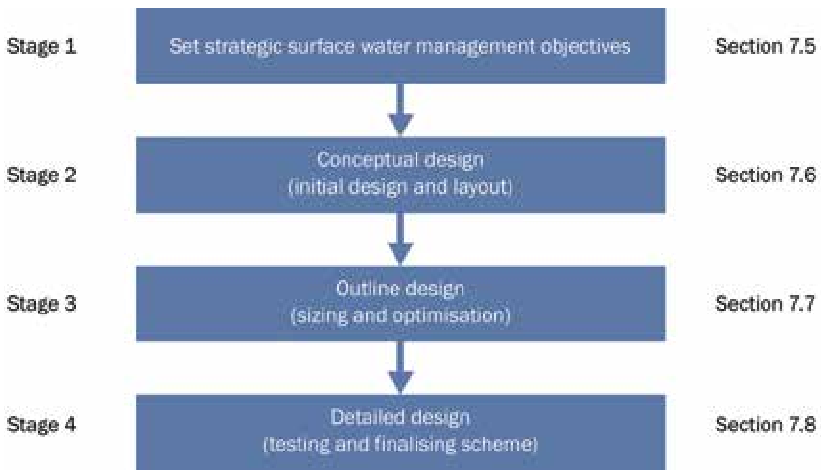

Figure 7.1 The four stages of SuDS design

The SuDS design process is part of a much larger design process for the development as a whole and will therefore be influenced by the progress of the overall project. This means that there may be the need for iteration between stages, while the overall development and individual building designs progress alongside the SuDS design. For example, the layout of the system conceived at conceptual design stage may need to be reviewed once the preliminary SuDS component sizing has been carried out and as the overall layout for the site is refined.

The guidance in this chapter is most relevant for new development or redevelopment projects, although retrofit considerations are referenced. Detailed guidance on the design process and implementation mechanisms for retrofitting SuDS is provided in CIRIA C713 (Digman *et al*, 2012).

7.2 SUDS AND THE PLANNING SYSTEM

7.2.1 Integrating SuDS design and land use planning processes

The land use planning system controls development and use of land in the public interest at different scales. It is a plan-led system, requiring forward planning through development plans, and it gives local authority development plan policies pre-eminence in the determination of applications for planning permissions. This permission is required for all development, as defined in various planning Acts and Regulations.

Local criteria relevant to SuDS may be set via a local planning authority's adopted planning instruments (including flooding and planning documents) and via standards set by drainage approving and/or adoption bodies (which may also refer to national standards where these exist). Both need to be checked before design starts, to ensure that designs are fully compliant with relevant requirements. Water management is an important planning consideration for any new development or redevelopment, with flooding, climate resilience, community value and changes to biodiversity and landscape being relevant material considerations, among others. SuDS can deliver benefits to, and be implemented at, a wide range of scales (from catchments to buildings) and the level of associated planning should be proportionate. Guidance on the incorporation of SuDS requirements into local spatial planning documents is provided in CIRIA C687 (Dickie *et al*, 2010) and University of Cambridge (2014).

The alignment and integration of the planning and drainage design process stages is set out in **Figure 7.2**.

For large sites, conceptual design is likely to form part of development master planning (**Section 7.2.3**), but for smaller sites, formal master planning may not be required. Outline designs will usually be required where outline planning permission is sought, and detailed design will be required for full planning permission. If outline planning permission is not a requirement for the development, then outline and detailed design would normally be undertaken as a single stage. The process steps described for outline design (**Section 7.7**), however, will still need to be carried out.

7.2.2 The importance of pre-application discussions

Pre-application discussions between planners and developers (or their consultants) is normally a requirement of the planning and/or drainage approval process – particularly for larger sites. It is highly recommended for all sites. These discussions can help significantly in ensuring that the expectations and objectives for the surface water management system, including approval and adoption requirements, are set out at an early stage in the design of development layouts and characteristics. This will also help to ensure that space is used as efficiently and cost-effectively as possible, and will maximise the benefits that can be achieved through effective integration of water management within the development.

In parallel with this, it is also advisable to have early engagement with the affected stakeholders (**Section 7.3**).

- ▶ Suggested material for discussion at pre-application stage is set out in **Appendix B** (**Section B.1.1, Table B.1**).

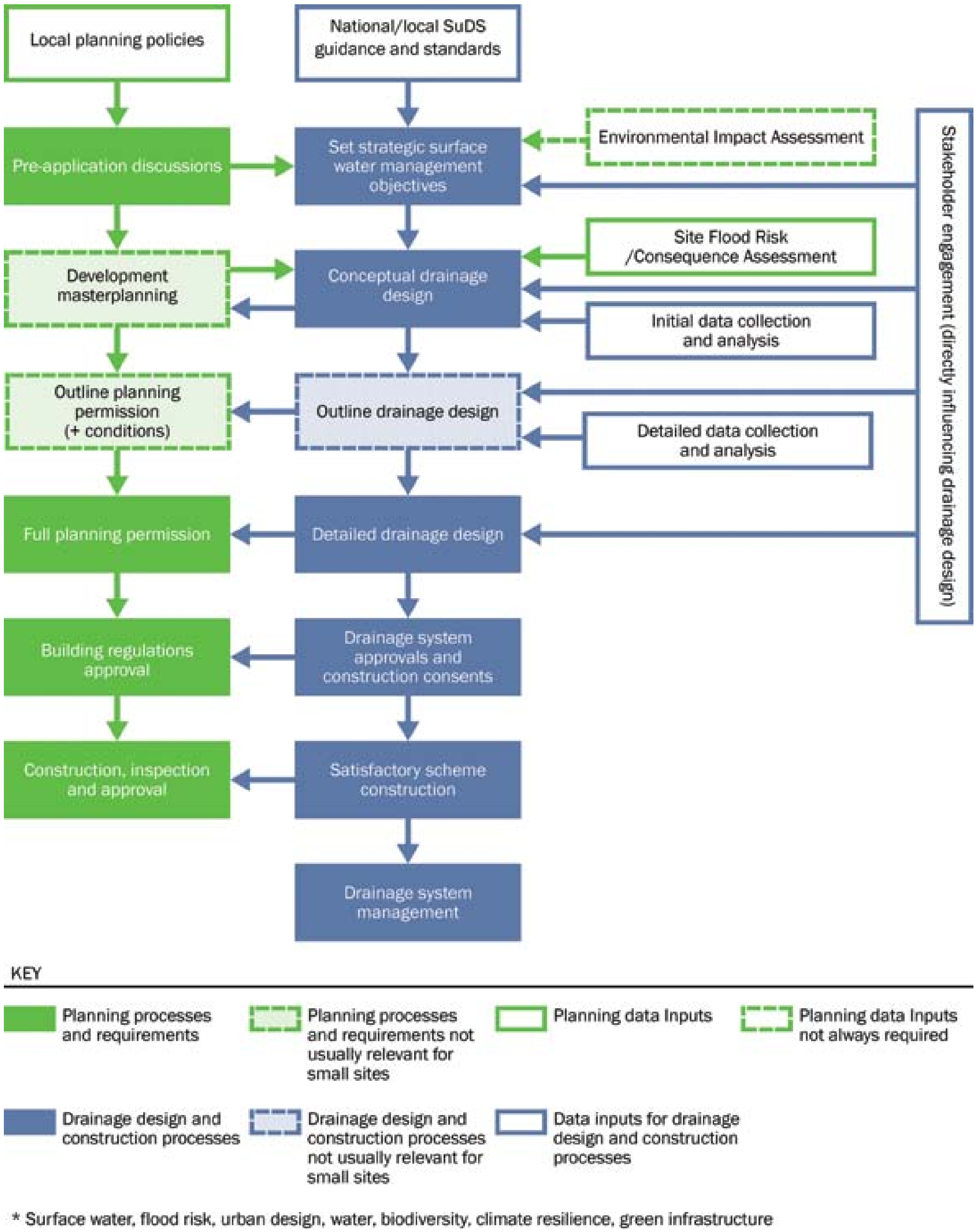

Figure 7.2 The drainage system design process: links with land use planning

7.2.3 Conceptual SuDS within development master planning

A master plan is an overarching planning document and spatial layout that is used to structure future land use and development. Its scope can range from a ten-year implementation strategy at the regional scale to an illustrative plan of a small-scale group of buildings. It provides a crucial opportunity for SuDS to be linked with a wide range of other development objectives (demonstrating the potential benefits and multi-functionality of SuDS components at this early stage) and for this to be recognised in the business plan for the development. Although some developments may be large enough to require master planning for preliminary planning approval or material change of use, there is often no formal requirement, and every design team will have its own individual approach (AECOM, 2013).

Master planning is a collaborative process that provides the strategic framework for considering the whole range of requirements and objectives for a development and how they might be delivered. It should be a holistic framework within which all relevant stakeholders can contribute and work together in creating high-quality 'places' for future generations. It creates the opportunity for the use and management of rainwater and surface runoff to be fully considered in a strategic and collaborative way by drainage engineers, urban designers, highway engineers, architects, landscape architects, ecologists and community stakeholders (**Section 7.3**). For large sites, the design team will benefit from inputs from all these disciplines as the drainage concepts evolve. For small sites, inputs should be sought where necessary. There are many examples of master plans where surface water management has been used to structure and frame the development (eg Ashton Green, Leicester (Atlas, 2012) and North West Cambridge (University of Cambridge, 2015).

To maximise the value of water to all stakeholders and to deliver the most efficient and cost-effective design solutions, water management should be considered at all design scales. It should influence and enhance individual building form and performance, and then connect plot-level management components into the wider strategic drainage network and landscape setting. By bringing together SuDS with building, urban, service delivery and landscape design and form, designers can achieve a water-sensitive urban design perspective (Abbott *et al*, 2013).

7.2.4 The challenges of delivering SuDS for phased developments

On large sites where development may be completed in phases, there will need to be a strategic site surface water management system that allows different parts of the site to be developed at different times, while ensuring that each of the design criteria can continue to be met. This strategic system should be designed to manage the flows from the final developed site, and specific conditions will need to be set for each development plot so that the original design assumptions are not invalidated. Delivery of each of the design criteria should be considered at both a site level and a plot level to maximise the benefits and to reduce risks associated with non-development or substantially delayed development.

Consideration should be given to the relative benefits associated with providing strategic storage versus higher levels of plot-based storage or a combination of both. The adoption arrangements for elements of the strategic system that may lie outside the phase being developed will also require careful consideration and facilitation. Relevant catchment or sub-catchment planning strategies may determine where off-site or strategic drainage components are required or proposed, and their design characteristics. Consideration should also be given as to any specific requirements for pollution prevention strategies (affecting either the development design or future operational strategies) to manage pollution risks. This is usually most relevant for industrial sites.

▶ Guidance on pollution prevention strategies is provided in **Chapter 27**.

7.2.5 SuDS design and the Environmental Impact Assessment

Environmental Impact Assessment (EIA) is the process by which the anticipated effects on the environment of a proposed development or project are measured. If the likely effects are unacceptable, the EIA will suggest design measures or other relevant mitigation measures to reduce or avoid those effects (eg pollution prevention strategies – **Chapter 27**). An EIA may not be required for smaller development sites.

The EIA may evaluate many of the strategic objectives for the site (**Section 7.5**) and may also undertake a number of the site and development characterisation steps required as part of the surface water management system conceptual design (**Section 7.6**). Where an EIA is available, it is likely to be a very valuable reference source for the SuDS designer – particularly the sections covering water resources and flood risk, water quality management, biodiversity, climate resilience, landscape, development character and visual amenity. SuDS may be highlighted in the EIA as a potential means of addressing some of the environmental impacts caused by the development.

7.2.6 SuDS design and the Flood Risk/Consequence Assessment

The Flood Risk Assessment (FRA) or Flood Consequence Assessment (FCA) for the site may be undertaken at a similar time to conceptual SuDS design. Delivering conceptual SuDS design as part of the FRA/FCA outputs will tend to make the design process more efficient and integrated, and produce the best outcomes. The FRA/FCA will identify key areas of the site that may or may not be suitable for SuDS components, and will also establish any flood hazards for the operation and performance of the drainage system. The FRA/FCA should also identify any specific requirements for surface water management on the site required by catchment- or sub-catchment-scale flood risk management strategies.

More detail on assessing the impact of pre-development flood risk and the potential impact on surface water management system design is provided in BS 8582:2013.

7.3 SUDS DESIGN AND STAKEHOLDER ENGAGEMENT

Successful delivery of SuDS often depends on co-ordination and communication between the developer/designer and a range of external stakeholders including local authority departments such as planning, drainage and flooding, ecology, open-space management and highways as well as environmental regulators, water and sewerage undertakers, local community group representatives, residents' organisations and other private sector stakeholders.

There is a need for stakeholder involvement throughout the process of surface water management system design. The land-use planning process should be used to bring together the views of both statutory and non-statutory consultees with other interested parties, such as non-governmental organisations and the general public. This provides a mechanism for planners and environmental regulators to engage with others on SuDS – raising awareness, educating developers and promoting community interaction and learning opportunities.

For retrofit schemes, stakeholder engagement can facilitate potential partnership funding opportunities, where benefits from the scheme will accrue to multiple stakeholders, and this can help with securing the most cost-effective and highest quality schemes. The design process for such schemes should also encourage and involve local communities – the most successful outcomes will be delivered where communities can (because of effective education and awareness raising) act as a 'client' and 'contributor', understanding the role and opportunities of rainwater and surface water management in the landscape.

Engagement with the local community (whether this is with neighbouring inhabitants for new developments or current residents for retrofit sites) should be part of both the land use planning and SuDS design processes. There are many different engagement processes that can be used (ie inform, consult, involve, collaborate, empower), but most will include an element of education and awareness-raising. Understanding will tend to foster an appreciation of the role and benefits of SuDS in environmental protection, and an enhanced sense of responsibility for their upkeep and protection.

▶ Guidance on working with communities is provided in **Chapter 34**.

7.4 STAGE 1: SETTING STRATEGIC SWM OBJECTIVES

The first stage of the SuDS design process is the setting of the strategic surface water management (SWM) objectives for the development.

Consultation with relevant stakeholders (**Section 7.3**) and reference to adopted local planning and regulatory guidance, policy (**Section 7.2.1**) and the site Environmental Impact Assessment (**Section 7.2.5**) and flood risk/consequence assessment (where available – see **Section 7.2.6**) should establish relevant local or site-specific strategic objectives including:

- flood risk management objectives

- water quality management objectives
- community, social and amenity planning objectives
- habitat and biodiversity strategy requirements and needs
- viable long-term maintenance bodies for the proposed SuDS and any relevant SuDS adoption requirements (eg standards, criteria and/or guidance)
- climate change adaptation/climate resilience requirements and needs
- water supply objectives and constraints.

Early consideration of surface water management will provide designers with the opportunity to use SuDS that respond to the local context and character, enriching both the natural and built environment. By fully integrating the management of surface water with the wider development objectives and by considering all space as potentially multi-functional, surface water management systems can be used to enhance development viability by delivering the design criteria described in **Chapters 3–6**. This can result in a range of benefits, such as:

- an alternative water resource to improve future water security
- higher value amenity, recreation and education facilities within public open space
- improved habitats and biodiversity
- improved climate resilience for the development
- reduced pressure on sewerage infrastructure and reduced surface water flooding
- a natural ‘structure’ to the layout of the site where transport routes, public open space and buildings are aligned with flow conveyance routes, and public open space is integrated with green and blue flow storage and treatment components
- a mechanism for enhancing and defining the quality, character and visual aesthetics of both the built environment and green/open space
- a surface water management system that can be easily and cost-effectively maintained.

▶ General guidance on using SuDS to deliver multiple benefits can be found in **Chapter 1**.

▶ Guidance on opportunities for multi-functionality can be found in **Chapters 5 and 10**.

▶ Guidance on delivering water quantity, water quality, amenity and biodiversity benefits can be found in **Chapters 3–6** respectively.

▶ Guidance on assessing the value of benefits can be found in **Chapter 35**.

7.5 STAGE 2: CONCEPTUAL DESIGN

The second stage of the SuDS design process is the conceptual design. The key outcome of this stage is to identify and assess potential SuDS components and linkages, in developing Management Trains for each area of the site.

The conceptual design stage process is shown in **Figure 7.3** and described in the sections below.

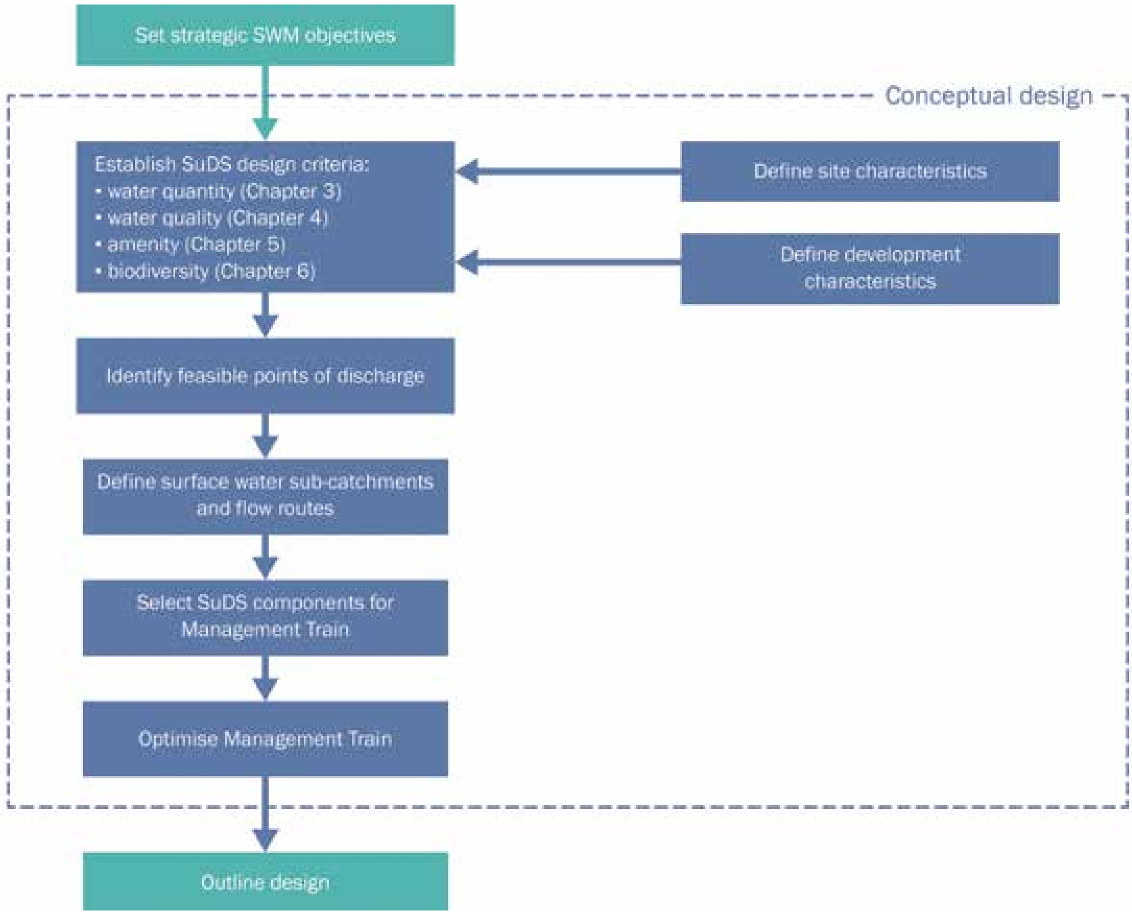

Figure 7.3 The conceptual design process

7.5.1 Define site and development characteristics

It is important to assess the site for the SuDS scheme before design begins. Where SuDS are to be retrofitted, this should include existing roof areas, hard surfaces, green spaces and land ownership boundaries, in order to make the best use of the space.

This step has two elements:

- **characterisation of the site** – development of an understanding of relevant features of the site and the surrounding area that could influence the SuDS design criteria and design options
- **characterisation of the development** – development of an understanding of relevant features of the proposed development that could influence the SuDS design criteria and design options.

Site characterisation covers an assessment of:

1 site topography
2 existing flow routes and discharge points
3 potential for infiltration
4 potential for surface water discharge
5 site flood risks
6 existing site land use
7 existing site infrastructure (above and below ground)

8 existing soils

9 local habitats and biodiversity

10 local landscape and townscape.

Development characterisation covers an assessment of:

11 proposed topography, land use and landscape characteristics

12 proposed flood risk management strategy

13 proposed site infrastructure

14 proposed building style and form

15 proposed adoption and maintenance of the surface water management system.

Each of these subjects is discussed in the sections below.

1 Site topography

- *Do the site contours mean that flow paths will naturally occur in particular locations?*
- *Are there any low-lying areas where water will naturally accumulate?*
- *Are there any particularly flat or steep parts of the site?*

Topography is a good indication of existing natural drainage pathways and will often help define appropriate natural routes for the surface runoff to follow, in order to efficiently drain the site from higher to lower levels using surface gradients, without relying on extra infrastructure or pumping.

Particularly steep slopes may not be suitable for conveyance routes, without measures to reduce gradients and/or flow velocities, and the siting of storage systems on slopes may require embankments, which should be avoided where possible.

Identification of low-lying areas will demonstrate where water will naturally accumulate, and these may be good locations for siting storage areas. Local historical knowledge and records of surface flooding will be valuable for this process.

▶ Guidance on designing for both sloping and very flat sites is provided in **Sections 8.4 and 8.5** respectively.

2 Existing flow routes and discharge points

- *How is the site currently drained?*
- *What are the existing flow paths across the site?*

The natural drainage pattern for the site and existing flow paths and discharge points should be established (as illustrated in **Figure 7.4**) and an assessment made as to how these are likely to be modified by development. This is determined largely by topography and ground conditions, together with a review of historical drainage measures that have modified the original drainage pattern including land drainage, culverts and sewer networks. Current discharge points (whether to groundwater, surface waters or sewerage systems) should be established and characterised.

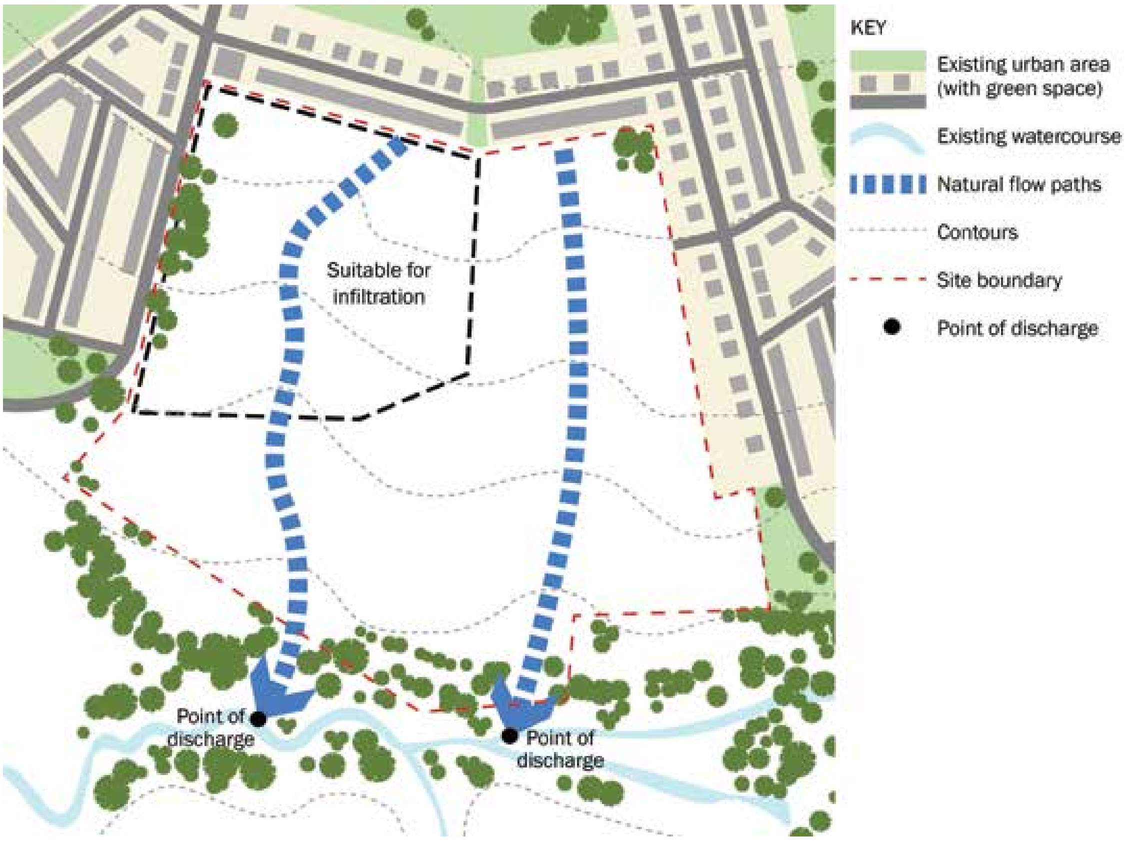

Figure 7.4 Characterising flow routes and discharge points

CASE STUDY 7.1 **Singleton Hill, Ashford, Kent**

Figure 7.5 Singleton Hill (courtesy Kent County Council)

Singleton Hill is a development that considered drainage from the outset of the master plan. As a result, buildings were designed around the existing drainage routes. Maintaining these natural flow routes eliminated the need to engineer conveyance routes. The main drainage channels were developed as a greenway for pedestrian and cycle access through the development to a local commercial area. This makes walking and cycling safer on the development and reduces car usage by residents and visitors.

3 Potential for infiltration

- *Is the soil or groundwater contaminated and, if so, what is the depth of any contamination sealing?*
- *What is the maximum likely groundwater level beneath the site?*
- *Is there any risk of groundwater flooding on or adjacent to the site?*
- *What is the infiltration capacity of the soil beneath the site?*
- *What is the designation of any groundwater resource beneath the site (eg source protection zones)?*
- *Is there a risk of subsidence or other soil instability from infiltrating water?**
- *Are there any risks associated with infiltrating water close to existing basements, building foundations, tunnels, road/car park pavements or other surface or subsurface infrastructure?**
- *Are there any constraints to water entry into existing pavement sub-base sections (on or adjacent to the site)?*

(*If the area over which infiltration is taking place is large and at shallow depth, and providing the SuDS allow evaporation of water, then the risk is often no greater than that posed by an area of grass.)

The site area should be characterised in terms of the potential for infiltration (eg good/poor/not possible). This will identify areas where infiltration within the site can potentially be used as a method of disposing of surface water runoff, areas where infiltration can be used to deliver Interception (using low infiltration capacities), and areas where infiltration cannot or should not occur.

- ▶ Guidance on the potential constraints to the use of infiltration and infiltration testing methods is provided in **Section 25.2**.
- ▶ Guidance on sites with high groundwater levels, contaminated soils or groundwater is provided in **Sections 8.2 and 8.3**.
- ▶ Guidance on the need to deliver Interception is provided in **Sections 3.2.3 and 3.3.1** and **Sections 4.2.2 and 4.3.1**.
- ▶ Guidance on designing Interception is provided in **Section 24.8**.

4 Potential for surface water discharge

- *What options are there regarding discharge destinations?*

Local surface waters that may be suitable for discharge of runoff should be evaluated in terms of their capacity, existing flood risk and any environmental or use designations. These will influence the viability of possible discharges and (when considered together with land use) provide an indication of the level of runoff treatment that might be required. If the SuDS are likely to discharge to a surface or combined sewer, then the surface waters receiving discharges from the sewerage system should be assessed.

Where discharges are proposed to existing sewers, early consultation should be undertaken with the relevant sewerage undertaker. Rights to discharge to any receiving watercourse should be established early in the design process, and the relevant stakeholders engaged appropriately.

- ▶ Guidance on prioritising where surface water runoff is discharged is provided in **Section 3.2.3**.

5 Site flood risks

- *Is there a risk of groundwater flooding?*
- *Is there a risk of sewer flooding?*
- *Are there local fluvial and/or coastal flooding risks?*
- *Are there any local surface water flooding issues? If so, where?*
- *Are there any planned mitigation actions?*

Pre-development flood risk should be established by the flood risk/consequence assessment for the site, which should have been considered during stage 1 (Setting strategic SWM objectives) but should be revisited here.

An assessment needs to be made of the extent to which the identified flood risk could impact on or be impacted by any site surface water management system. Consideration should be given to fluvial, coastal, groundwater, and surface water flood risks on the site, before the proposed development.

- Guidance on managing on-site flood risk is provided in **Sections 3.2.6 and 3.3.3**.
- Guidance on SuDS in floodplains is provided in **Section 8.8**.

6 Existing site land use

- *How is the site currently used and will this continue after development (for retrofit schemes)?*
- *What opportunities are there to use the site more effectively for surface water management (for retrofit schemes)?*
- *How will the use of the site before the development impact on the extent to which runoff needs to be managed by the SuDS for the proposed site?*

Where looking to retrofit SuDS, site surveys and community engagement can help to understand how the space is currently used.

Where the site has been developed previously (ie redevelopment sites), there should always be an aspiration to manage runoff to represent greenfield characteristics. This will help reduce any receiving watercourse flood risk (both now and under future climate change scenarios), thus contributing to more sustainable development. However, it is recognised that redevelopment sites tend to be more constrained in terms of space and infiltration may be more restricted, so drainage approving bodies (in conjunction with the environmental regulator) may agree that reductions to an agreed proportion of the previously developed rates/volumes are acceptable.

7 Existing site infrastructure

- *What is the location, depth and capacity of existing drainage?*
- *Where are existing services located (including depth)?*
- *Are there any existing unique assets in the street(s) (eg sewer vent)?*
- *Are there any flood risk management assets on the site?*

When building on brownfield or pre-developed sites, existing on-site infrastructure should be documented and mapped. It is important to understand the location and capacity of existing drainage, to determine what infrastructure could or should be reused in the SuDS scheme. Some of these features may have byelaws associated with them, and this should be checked at an early stage, along with any associated implications. Other buried infrastructure, such as utilities and other services, need to be located and considered – particularly with respect to access for inspection and maintenance. Existing services can sometimes be diverted (although this is usually only possible for larger sites), and this option can also be considered.

Asset databases of buried infrastructure available from utility providers or the local authority should not be considered as definitive and should be checked with surveys.

For sites where there is congestion of buried services (most common for retrofit sites), a specialist company should be employed to carry out a survey of buried services before starting any design.

Registered flood risk management assets should be identified from the local flood authority, and any interaction with the proposed drainage system should be considered and managed appropriately.

8 Existing soils

- *Is the existing soil on the site suitable for use in SuDS design?*

An assessment should be carried out of the existing topsoil and subsoils on site, so that their suitability for reuse on the site can be determined and the handling and management of these soils can be carried out appropriately (**Section 29.3.3**). It may be appropriate for this to be undertaken by a qualified soil scientist.

9 Local habitats and biodiversity

- *Which habitat types and species of flora and fauna are, or were (historically), prevalent in the area?*
- *Are there any locally important habitats, and how are these connected?*
- *Is there a local biodiversity strategy?*

Existing site habitats should be characterised so that consideration can be given to which species of flora and fauna might be able to exploit new habitat potentially created by the SuDS scheme. This should normally be undertaken by an ecologist and should be documented within an ecological report for the site. The Chartered Institute of Ecology and Environmental Management provides a comprehensive source of guidance on species survey methods and ecological impact assessment techniques.

Existing and historic locally important habitats (eg marshland, ponds/wetlands, grasslands, riparian corridors) should be evaluated in order that they are supported and/or recreated where valuable and appropriate. Understanding existing habitat areas and how these are connected (or could be connected) will help to determine the extent to which the new SuDS might be able to enhance local ecological networks and corridors. Local biodiversity strategies should have been considered during stage 1 (setting strategic SWM objectives) but should be revisited at this stage.

▶ Guidance on supporting and protecting natural local habitats and species, delivering local biodiversity objectives and creating habitat connectivity is provided in **Chapter 6**.

10 Local landscape and townscape

- *Are there any conservation designations or planning constraints for the site that will affect the SuDS design?*
- *What are the existing green or blue assets on or near the site (eg parks, playgrounds, rivers, lakes, canals)?*
- *What are the potential climate change pressures for the area (eg urban heat island effect, water scarcity)?*

Existing local landscape and townscape characteristics will help define:

- the likely suitability and detailing of different SuDS components
- the likely value of green and blue space, and natural assets (this may be a function of local housing densities)
- potential climate change pressures (eg urban heat island effects, water scarcity)
- climatic characteristics (eg is the area naturally dry or wet?)
- the relationship between existing development and any common local water features.

Landscape character assessments (Tudor, 2014) can be used to help support this characterisation process.

Planning and conservation designations for the local area may also be relevant to SuDS design and should have been considered during stage 1 (setting strategic SWM objectives) but should be revisited at this stage.

- Guidance on landscape character is provided in **Section 29.2**.
- Guidance on enhancing visual character is provided in **Section 5.2.3**.
- Guidance on designing SuDS within the context of existing urban areas is provided in **Chapter 10**.

11 Proposed topography, land use and landscape characteristics

- *How will the topography of the developed site change compared to the existing site?*
- *Is the proposed topography likely to present challenges?*
- *What are the proposed land uses for the site?*
- *What are the landscape requirements for the site?*
- *What will be the building density for the development?*
- *How will the site be used and maintained?*
- *How could locally important habitats be connected?*

Any substantive changes to the topography required by the development will need to be taken into account, including any land raising required for flood risk management or contaminated land remediation purposes.

Where the topography is likely to provide particular challenges for the implementation of a surface water management system, consideration should be given to whether any beneficial changes could be made.

The extent of the development, likely building density, proposed land uses across the site, and the proposed landscape strategy will be key influences on the overall surface water management design philosophy. They will define the mix of impermeable and permeable surfaces to be drained or used for drainage, they will define the likely pollution hazard posed, and they will have a strong influence on the suitability of different SuDS components. Any pollution prevention strategies proposed for the site should be considered in terms of any potential impact on water-quality risk management for the site.

External landscape requirements (eg car parks and urban squares), amenity and recreation areas (eg sports fields and playgrounds) and other public open space planned for the site should be evaluated so that, where possible, it can be integrated with surface water management systems to deliver open space that is multi-functional and of high amenity and biodiversity value. Natural flow paths and manmade connection routes (eg roads, cycle paths and green corridors) are likely to be of particular importance in structuring a potential network for runoff conveyance and storage through the site. Consultation with stakeholders will be required to establish appropriate ownership and maintenance strategies for multi-functional land.

The characteristics of likely vehicle usage (including types of vehicles and likely speeds) on the site will be important. This can influence the type of surfacing and sub-base that might be suitable, the extent and location of parking requirements at roadsides (this may influence options for managing road runoff), the likely requirements for traffic calming measures and roundabouts (and the potential for integrating these with SuDS), and the potential for using roads as surface water runoff exceedance routes. Any requirements for special accessibility requirements, such as dropped kerbs, disabled parking or access for sweeping and/or winter gritting machines, may also impact on SuDS design and detailing.

An understanding should be developed of how the aesthetic appeal and tranquillity of diverse vegetated green spaces and open water features could add character and help create a sense of place, give the community a healthy outdoor environment that encourages outdoor activity and enjoyment and provide space where children can play and learn about water and the water environment.

Community engagement can provide valuable information regarding the community's aspirations for future use and the opportunities and constraints for SuDS, such as potential traffic calming measures and car parking requirements.

The potential use of underutilised land should be discussed with the appropriate landowners and tenants, with respect to making hard surfaces permeable, improving the landscaping or green infrastructure provision, or using the land directly as part of the surface water management strategy.

- ▶ Guidance on designing SuDS to suit the proposed land use is provided in **Chapter 10** (in particular see the typologies in **Section 10.3**).
- ▶ Guidance on enhancing visual character and supporting community environmental learning is provided in **Sections 5.2.3 and 5.2.7**.
- ▶ Guidance on the likely pollution hazard associated with different land use types and the potential implications for SuDS design is provided in **Sections 4.2.2 and 4.3.2** and **Chapter 26**.
- ▶ Guidance on community engagement is provided in **Chapter 34**.

12 Proposed flood risk management strategy

- *How could surface water management for the site be affected by or affect the flood risk management strategy?*

An assessment needs to be made of the extent to which any identified flood risk mitigation strategies established by the FRA/FCA could impact on or be impacted by any site surface water management system.

This should have been considered during stage 1 (setting strategic SWM objectives) but should be revisited at this stage.

- ▶ Guidance on managing on-site flood risk is provided in **Sections 3.2.6 and 3.3.3**.
- ▶ Guidance on SuDS in floodplains is provided in **Section 8.8**.

13 Proposed site infrastructure

- *How could the proposed site infrastructure be affected by or affect the scheme design?*
- *Where are existing and planned services located (including depth)?*
- *Can existing services be diverted (usually only possible for larger sites)?*
- *Can planned services be designed to fit around the SuDS?*

Any planned subsurface or surface infrastructure (including proposed services) for the development should be mapped and evaluated to determine the potential impact on SuDS layout and design. Where SuDS are considered early in the development design process, there may be the flexibility to route planned services around SuDS locations.

14 Proposed building use, style and form

- *How can the architecture and building design assist, improve and be part of surface water management (eg green roofs)?*
- *How can drivers and opportunities for building-scale rainwater harvesting (RWH) systems facilitate the use of RWH system storage for surface water management?*
- *How might water features best be used in the context of the proposed building use, style and form?*
- *How can water be conveyed from roofs and impermeable surfaces to SuDS components (downspouts, rain chains etc)?*
- *How can water enrich urban spaces and building fabric?*
- *How can the surface water management system help secure climate adaptability and resilience for the buildings (through securing a more sustainable water supply, providing urban shade, extra insulation and cooling etc)?*

Understanding the proposed building types, density, quality, character, style and any applicable sustainability targets (eg DCLG, 2008) will maximise the benefits for the development.

At the building scale, SuDS are increasingly being seen as part of the fabric of buildings, for example, as landscapes, green walls and roofs, and as the key purpose of internal courtyards. Not only does this enhance the aesthetic quality of the buildings, but it brings among other things, climate and internal air quality benefits.

- Guidance on maximising multi-functionality and supporting development resilience/adaptability to future change (including climate change) is provided in **Sections 5.2.2 and 5.2.5**.
- Guidance on green roofs is provided in **Chapter 12**.
- Guidance on RWH systems is provided in **Chapter 11**.

15 Proposed adoption and maintenance

- *Who will have final ownership or adopt the SuDS?*
- *What approval criteria and processes will be set by the owner/adoption body?*
- *Who will be responsible for future maintenance of the SuDS?*
- *What is the likely level of maintenance?*

Agreement on the organisation that will take long-term responsibility for the ownership and maintenance of the SuDS should have been established when the SWM objectives for the site were defined. Any remaining uncertainty should be removed at this stage, because without a confirmed adoption body, the proposed scheme (and thus development) will not be viable.

The adoption body may have independent approval criteria and processes, and these should be clearly understood by the designer, and evaluated for potential impacts on the design.

The body may also have their own protocols on the level of maintenance that they will provide for schemes, and this should also be given full consideration in the design.

Where SuDS are proposed in public open space, it will be necessary to ensure that the design meets the requirements of the local authority. Consideration needs to be given to the responsibilities for maintenance of any public open space where the primary function will be other than surface water management. For example, as part of the design of detention basins or exceedance storage areas that have an amenity use, a decision will need to be made regarding optimum maintenance for surface water management versus the designated amenity use.

7.5.2 Establish SuDS design criteria

A suite of SuDS design criteria should be developed for the SuDS scheme that:

1. aims to deliver on each of the criteria set out in the individual criteria chapters to the maximum extent practical for the site:
   - water quantity (**Chapter 3**)
   - water quality (**Chapter 4**)
   - amenity (**Chapter 5**)
   - biodiversity (**Chapter 6**)

(Note: the standards set out in **Chapters 3 and 4** should be met in full, unless there are local or national standards that take precedence).

2. takes account of the strategic surface water management objectives established for the site (**Section 7.5**)
3. takes account of the opportunities, challenges and constraints identified by the site and development characterisation process (**Section 7.6.1**)

4 uses the guidance on maximising benefits from the scheme set out in the criteria chapters together with **Chapter 8–10**.

It may be useful to develop some indicators (suggested in the criteria chapters) for each of the criteria that can be used as a means of later assessing the extent to which each of the criteria are met by the as-designed scheme (**Section 7.8.2**).

7.5.3 Identify feasible points of discharge

The destination for surface water runoff should be prioritised, as defined in **Section 3.2.3**.

Checks should be made of any potential receiving surface waters environmental designations and discharge constraints and consents.

Where discharges to sewers are being considered, the sewerage undertaker should be consulted so that the designer understands the likely available sewer capacity and opportunities and/or constraints with respect to any potential connections.

- Guidance on prioritising where surface water runoff is discharged is provided in **Section 3.2.3** and **Chapter 10**.
- Guidance on the potential constraints to the use of infiltration and infiltration testing methods is provided in **Section 25.2**.

7.5.4 Define surface water sub-catchments and flow routes

Flow routes and development clusters should be used to define surface water sub-catchments, particularly on larger sites (**Figure 7.6**). These will then form discrete drainage areas, each with their own drainage characteristics with the runoff from them then conveyed downstream to the drainage outfall. The definition of sub-catchments and flow routes is therefore a linked process.

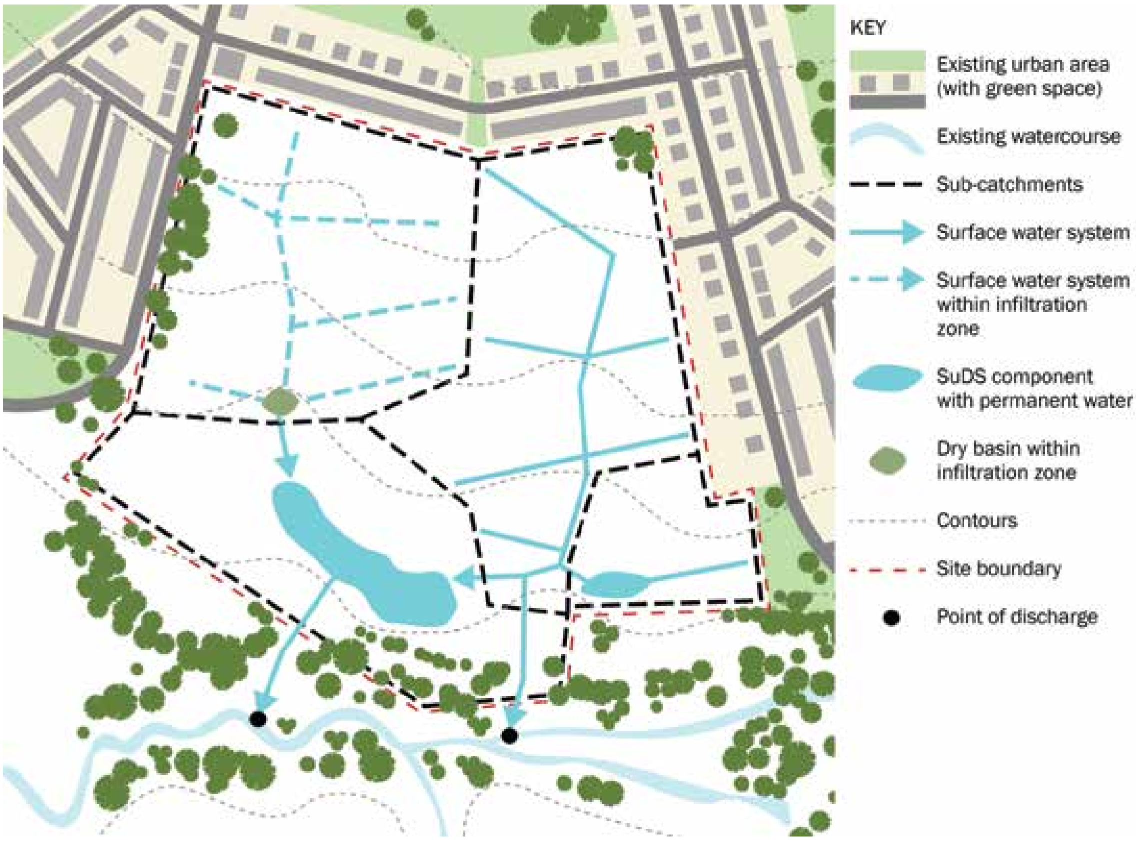

Figure 7.6 Defining surface water sub-catchments

It is often sensible to cluster land use types, as these will tend to have different requirements with respect to treatment (**Section 4.3.2**). Each sub-catchment should deliver Interception for the impermeable areas and should, where possible, treat the runoff and provide a degree of flow and volume control (using infiltration where practical). For large events, it may be appropriate to allow runoff to bypass sub-catchment controls to reach larger storage structures further downstream.

Where appropriate, planned parks and open spaces should be located at the downstream end of sub-catchments to provide space for larger-scale, surface water attenuation and controls (as illustrated in **Figure 7.7**).

Flow routes can often form part of open space corridors and be used to help link existing habitat zones with biodiverse pathways. Surface water conveyance paths should work with the topography to safely and effectively direct surface water to the desired locations, while simultaneously delivering integrated storage and treatment wherever possible. Water should be kept at or near the surface (ie not, where possible, in pipes), reducing the need for deep excavations and helping deliver all the benefits associated with surface systems.

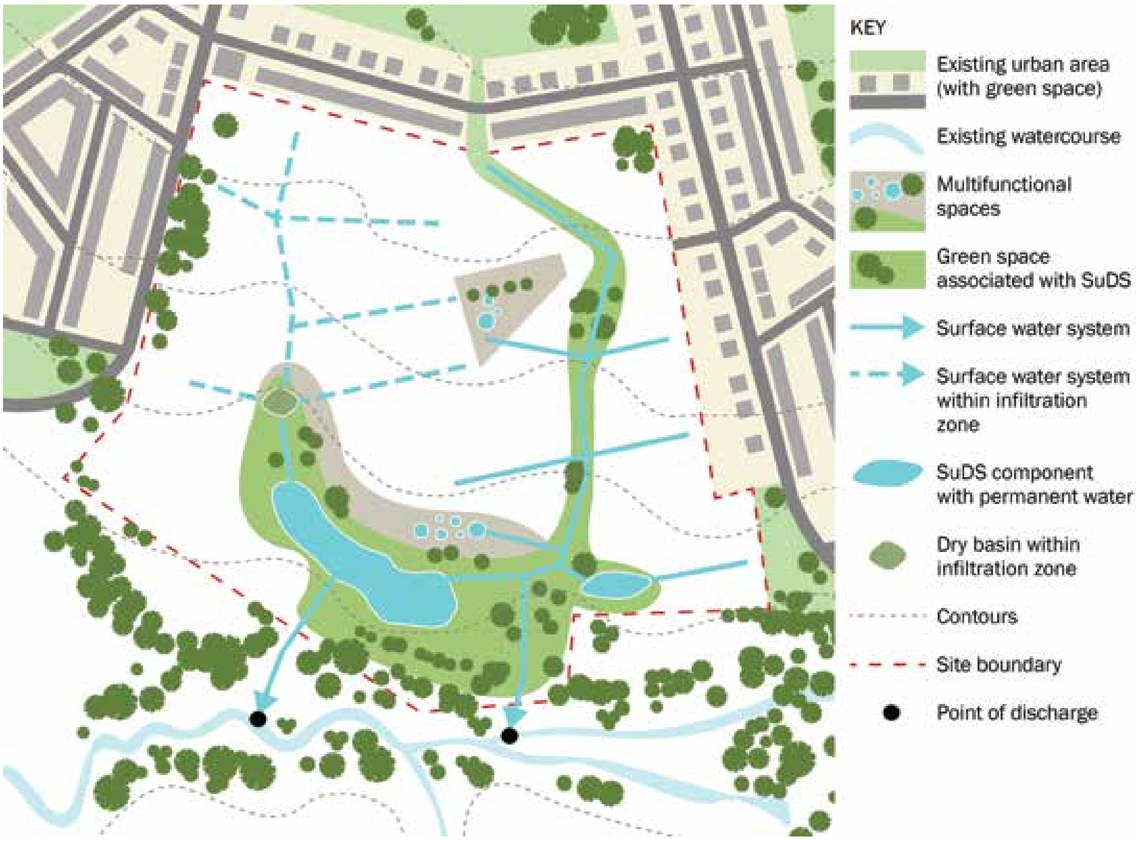

Figure 7.7 Defining parks, open spaces and corridors

If appropriate and practicable, configuration of the major road network and development blocks should also be defined by sub-catchment boundaries within the site (as illustrated in **Figure 7.8**). The street network should be structured to complement and manage flow pathways by:

- integrating SuDS components into street cross-sections, ensuring street widths are adequate
- using SuDS to improve the streetscape, providing multi-functionality by integrating with other street features including tree planting, traffic calming, parking bays, verges and central reservations
- making best use of available space to accommodate a wider range of depths, widths and profiles, where feasible.

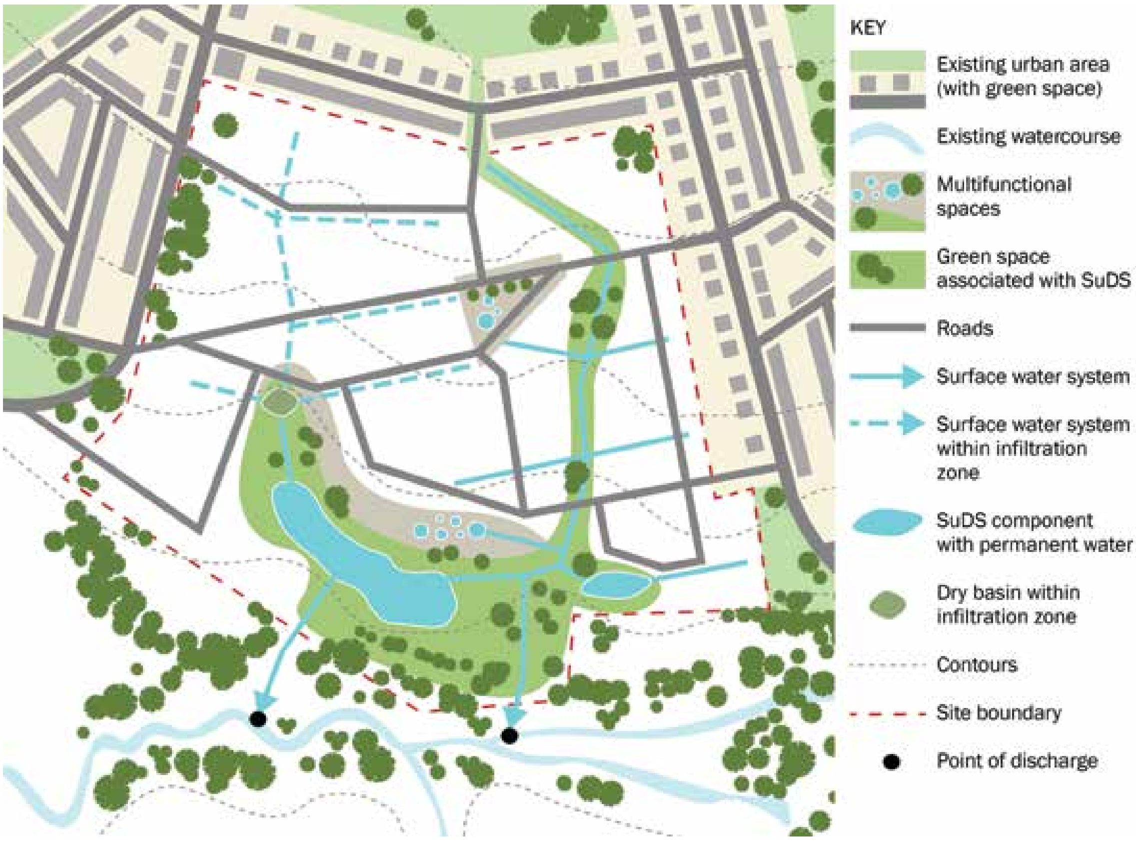

Figure 7.8 Defining the road network

If there are adopted roads as part of the development, then consultation with the highways authority needs to be undertaken early in the design process, in order that acceptable highway drainage designs can be developed, and any required integration of highway drainage systems with the drainage of other parts of the site can be agreed.

- Guidance on designing SuDS for sloping and very flat sites is provided in **Sections 8.4 and 8.5**.
- Guidance on designing SuDS for roads is provided in **Chapter 9**.
- Guidance on designing SuDS to work within a streetscape and delivering multi-functionality is provided in **Chapter 10**.

7.5.5 Select SuDS components for the Management Train

The SuDS components selected will depend on the design criteria, and on how the surface water management system is linked and integrated with the development and its landscape setting. Individual components can be designed in a number of different ways – both in a technical sense (eg the same component can either be lined to prevent infiltration, or have a permeable base) and a visual sense (components can be landscaped to look appropriate in a contemporary or more traditional setting). Components can often be used to both convey and store runoff, usually depending on the size of the runoff event (eg swales). **Table 7.1** summarises the likely potential of different SuDS components in delivering the design criteria, and provides a design aid as the steps of component selection and Management Train design are worked through – as shown in **Figure 7.9**.

TABLE 7.1 SuDS component delivery of design criteria

Component type	Description	Collection mechanism	Design criteria						Further information (Chapter ref)
			Water quantity (Chapter 3)			Water quality (Chapter 4)	Amenity (Chapter 5)	Biodiversity (Chapter 6)	
			Peak runoff rate	Runoff volumes					
				Small events (Interception)	Large events				
Rainwater harvesting systems	Systems that collect runoff from the roof of a building or other paved surface for use	P		●	●		●		11
Green roofs	Planted soil layers on the roof of buildings that slow and store runoff	S	○	●		●	●	●	12
Infiltration systems	Systems that collect and store runoff, allowing it to infiltrate into the ground	P	●	●	●	●	●	●	13
Proprietary treatment systems	Subsurface structures designed to provide treatment of runoff	P				●			14
Filter strips	Grass strips that promote sedimentation and filtration as runoff is conveyed over the surface	L		●		●	○	○	15
Filter drains	Shallow stone-filled trenches that provide attenuation, conveyance and treatment of runoff	L	●	○		●	○	○	16
Swales	Vegetated channels (sometimes planted) used to convey and treat runoff	L	●	●	●	●	●	●	17
Bioretention systems	Shallow landscaped depressions that allow runoff to pond temporarily on the surface, before filtering through vegetation and underlying soils	P	●	●	●	●	●	●	18
Trees	Trees within soil-filled tree pits, tree planters or structural soils used to collect, store and treat runoff	P	●	●		●	●	●	19
Pervious pavements	Structural paving through which runoff can soak and subsequently be stored in the sub-base beneath, and/or allowed to infiltrate into the ground below	S	●	●	●	●	○	○	20
Attenuation storage tanks	Large, below-ground voided spaces used to temporarily store runoff before infiltration, controlled release or use	P	●						21
Detention basins	Vegetated depressions that store and treat runoff	P	●	●		●	●	●	22
Ponds and wetlands	Permanent pools of water used to facilitate treatment of runoff – runoff can also be stored in an attenuation zone above the pool	P	●			●	●	●	23

Key

P – Point, L – Lateral, S – Surface, ● – Likely valuable contribution to delivery of design criterion, ○ – Some potential contribution to delivery of design criterion, if specifically included in the design

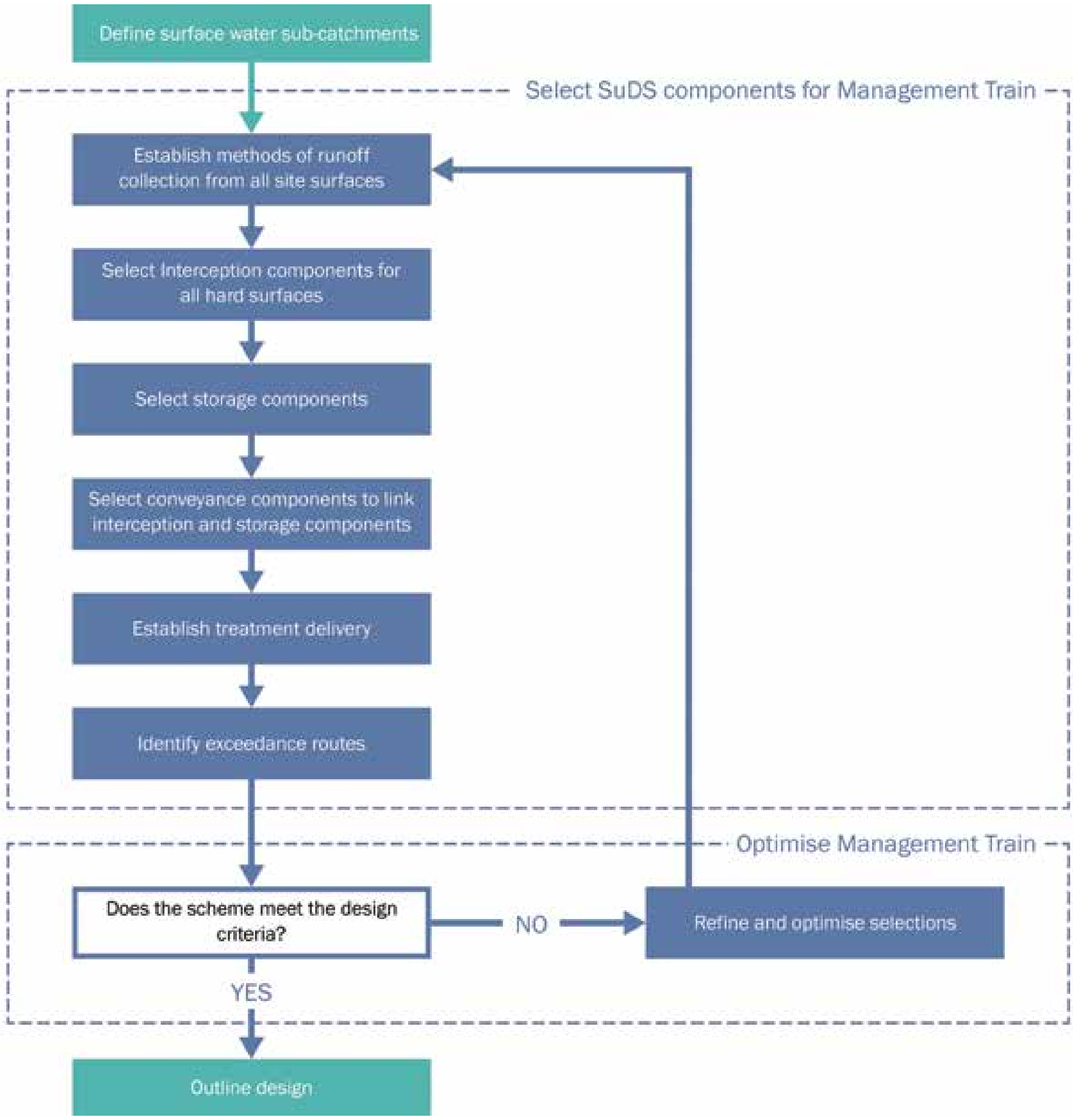

Figure 7.9 SuDS component selection process

- Guidance on the design of individual SuDS components is provided in **Chapters 11–23**.
- Guidance on SuDS components for specific sites is provided in **Chapter 8**.
- Guidance on SuDS component for roads is provided in **Chapter 9**.
- Guidance on SuDS components most likely to be suitable for urban areas is provided in **Chapter 10**.

Establish methods of runoff collection from all site surfaces

There are many ways in which runoff can be efficiently collected from development surfaces:

- Surfaces can be made permeable (eg through the use of pervious surfaces, or by using green roofs).
- The SuDS component can be designed to run alongside the impermeable surface so that runoff can be discharged directly, for example onto a filter strip, swale or other surface channel.
- Runoff can be diverted into conveyance or storage components using distributed collection methods, for example kerb openings and gullies.

- Guidance on inlet and outlet design is provided in **Chapter 28**.

Select Interception components for all hard surfaces

The first consideration in designing the SuDS Management Train for a site should be the delivery of Interception for each impermeable area, wherever possible. Interception is delivered where SuDS components are an integral part of the runoff surface or collection method (eg permeable pavements, green roofs, rainwater harvesting systems), and in such scenarios, the surface may also be able to provide Interception for adjacent runoff surfaces.

In areas where infiltration is possible, soakaways can be considered for roof water, and infiltration from swales, bioretention areas, dry basins and permeable surfaces can be used to manage as much surface water as possible (providing sufficient treatment is delivered before any discharge to groundwater). Where infiltration is impractical or inappropriate, very low infiltration rates and/or depths of soil storage can often be used for Interception, followed by conveyance to downstream attenuation and treatment components.

- ▶ Guidance on the design of Interception is provided in **Section 24.8**.
- ▶ Guidance on the design of infiltration components is provided in **Chapter 25**.
- ▶ Guidance on the design of RWH systems is provided in **Chapter 11**.

Select storage components

There are likely to be a number of areas within the development that could potentially be combined with the delivery of attenuation storage, for example beneath permeable paving or recreation facilities, within small detention zones, ponds or channel conveyance routes. Distributing the storage areas across the site within multi-functional spaces, can be effective in terms of land-take, potentially reducing the need for a large downstream attenuation facility.

If rainwater harvesting and infiltration cannot be used on a site, there will be a need to manage the extra volumes of runoff from the site in some other way. This extra volume can either be spilled from the main drainage system into a separate storage area which is drained very slowly (this is termed Long-Term Storage), or the extra volume can be incorporated into the main attenuation storage for the site (but this is likely to substantially increase the required storage volumes). Long-Term Storage areas will only flood infrequently, so can often be recreation or other amenity areas.

Very initial estimates of required storage areas are usually pragmatic at this stage. These can be done using past experience, simple spreadsheet tools (that follow the processes set out in **Chapters 24 and 25**) or using the tools on **www.uksuds.com**

Where the development is to be phased, storage should, where possible, be delivered on individual plots. Where the SuDS design for individual plots relies on strategic storage, agreement on access, ownership and maintenance of these elements needs agreement at an early stage of the design.

- ▶ Guidance relating to the delivery of storage components is set out in **Sections 3.2.3, 3.3.1 and 3.3.2**.
- ▶ Guidance on the design of attenuation and Long-Term Storage components is provided in **Sections 24.9 and 24.10**.
- ▶ Guidance on design of infiltration is provided in **Chapter 25**.

Select conveyance components to link Interception and storage components

As water is conveyed downstream, SuDS components should be linked using conveyance systems (eg swales, linear wetlands, channels, rills, pipes), which themselves may provide useful treatment, infiltration and/or storage.

Vegetated surface conveyance components will tend to deliver greater water quality, amenity and biodiversity benefits. They can also form part of open space corridors along important drainage features, and link existing habitat zones with biodiverse pathways.

On steep sites, surface water conveyance routes will either need to be directed across the slope to reduce gradients and minimise erosive velocities or other mechanisms will be needed to reduce gradients, such as natural waterfalls, checkdams and baffles. Keeping water on the surface reduces the need for cover, which can create requirements for very deep excavations for piped systems.

On flat sites, careful design will be required, to ensure that conveyance gradients do not mean that downstream systems are very deep.

- Guidance on designing SuDS for sloping and very flat sites is provided in **Sections 8.4 and 8.5**.
- Guidance on designing SuDS for roads is provided in **Chapter 9**.
- Guidance on designing SuDS to work within a streetscape and delivering multi-functionality is provided in **Chapter 10**.
- Guidance on the design of conveyance systems is provided in **Section 24.11**.
- Guidance on design of infiltration is provided in **Chapter 25**.

Establish treatment delivery

It is important that a SuDS scheme is developed with consideration of the pollution treatment requirements of different land use areas. Areas of the site with low contamination potential will represent opportunities for rainwater harvesting, and areas with low and medium contamination levels can usually be safely infiltrated. It is vital to ensure that relatively clean runoff is not mixed with poorer-quality runoff, thus rendering it less suitable for infiltration or harvesting. Where possible, different land uses (that have different pollution potential) should be clustered, so that Management Trains can be designed most efficiently. By implementing SuDS at a plot level, sources of pollution can be easily identified, and remedial actions and maintenance work can be undertaken by the plot owner/operator. Agreed pollution prevention strategies (eg specified as a condition of use) may influence the hazard posed by particular land use types, and these should be considered at this stage.

Sufficient treatment must be provided for both individual and/or combined sub-catchments, and an early review of likely treatment requirements for different land uses on the site should be undertaken following the design criteria in **Chapter 4** and supporting guidance on design methods in **Chapter 26**. Where the development is to be phased, the drainage of individual plots should not rely on drainage systems on plots not yet developed to meet the standards and criteria set for the site. Where the development is to be phased, water quality management should, where possible, be delivered on individual plots. Where the SuDS design for individual plots relies on strategic treatment components, agreement on access, ownership and maintenance needs agreement at an early stage of the design.

- Guidance on pollution prevention strategies is provided in **Chapter 27**.
- Guidance on the likely pollution hazard associated with different land use types and the potential implications for SuDS design is described in **Sections 4.2.2 and 4.3.2 and Chapter 26**.

Identify exceedance routes and storage locations

Safe exceedance routes and storage areas should be considered and integrated within the development design (**Figure 7.10**). Exceedance routes can include roads on the site, and exceedance storage areas can include car parks, recreation areas and other areas of public open space, as long as their use for this purpose will not impede their normal function to the extent of putting people or vehicles at risk and that they can be maintained in the long term. Appropriate legal permissions and requirements for use of the land as an exceedance route should be sought at an early stage.

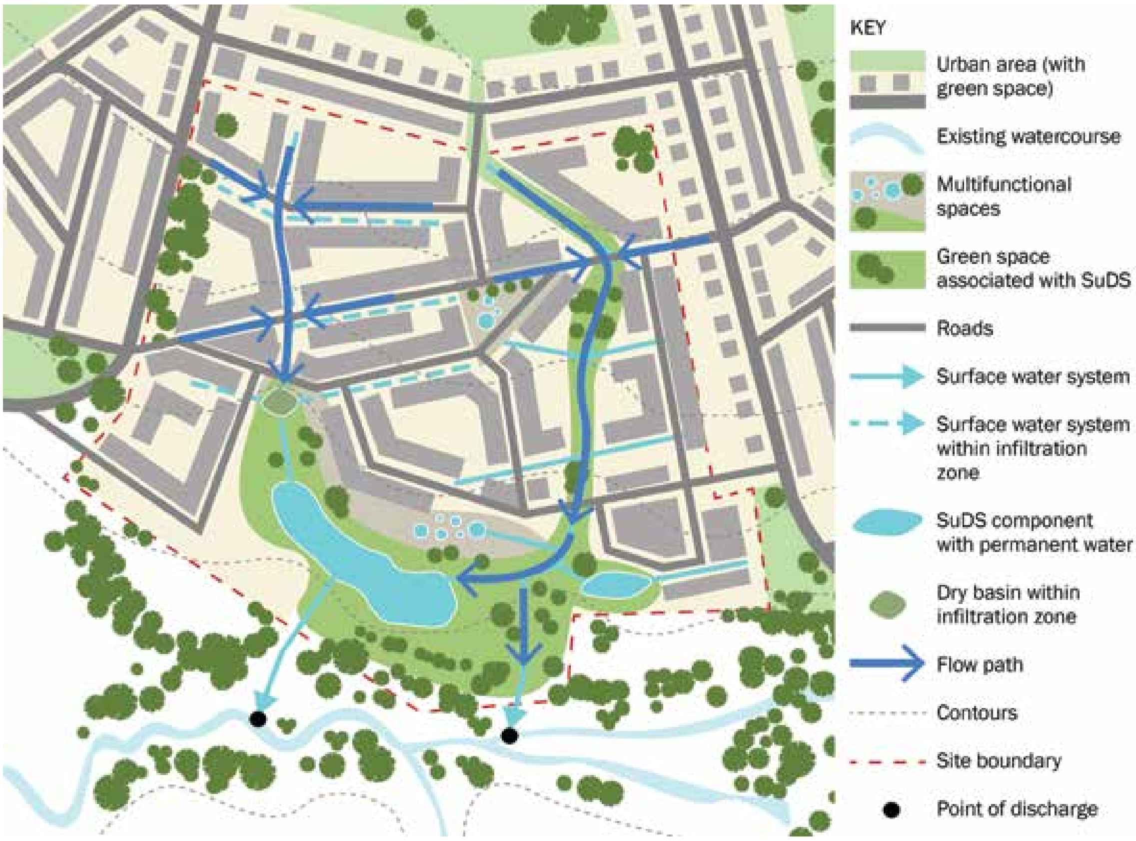

Figure 7.10 Defining exceedance routes

- Guidance on designing for exceedance is provided in **Section 24.12**.
- Guidance on designing SuDS for roads is provided in **Chapter 9**.

7.5.6 Refine the Management Train

Once the preliminary scheme has been designed for the site, the scheme as a whole should be reviewed against the design criteria, potentially using indicators where these have been developed. Where the design fails to meet the criteria, or benefits have not been maximised, SuDS components should be revisited to determine if there are more appropriate alternatives – or whether the components can be designed in such a way as to increase their value to the development.

At this stage, rough initial estimates of likely scales of SuDS components may be useful to designers – so that adequate space for SuDS in the streetscape and public open space can be allowed for.

Consideration should also be given at this stage to any potential construction issues associated with the selected components, and likely maintenance requirements (including access) to confirm the scheme's long-term viability.

Where development is to be phased, the SuDS design will need to take full account of this.

7.5.7 Conceptual design: Reporting

The reporting at this stage should set out the conceptual drainage strategy and confirm the approval and adoption processes and stakeholders involved. The report should include:

- definition of strategic objectives for the development in relation to the management of surface water, including any sustainability targets for water management, climate resilience, biodiversity, green infrastructure etc for the development, FRA requirements, and local SuDS approval and adoption policy requirements

- identification of likely synergies and challenges, such as potential contribution of the site surface water management system to wider catchment objectives, such as biodiversity delivery and flood risk management
- any requirements/objectives imposed by a wider site surface water management strategy (ie where the site is a parcel of land that forms part of a larger development area)
- water quantity, water quality, amenity and biodiversity design criteria and standards relevant for the site
- constraints and opportunities for SuDS delivery, including any likely change in permeability of the site following development, proposed land use, site contamination levels, infiltration potential, public open space/green space/amenity provision requirements, local biodiversity characteristics, building types and forms, street types and forms
- initial scoping of potential costs and benefits of different SuDS options, in order to estimate any influence on development viability
- the outputs of any initial stakeholder consultations and implications for SuDS design and community engagement strategies
- the definition of surface water sub-catchments, land use types, flow routes, runoff destinations and Management Train options
- design methods to be used (eg for greenfield or previously developed runoff rate assessments) and justification
- likely SuDS components and initial estimate of space required (including access for maintenance), including the potential integration with the built form, connective pathways, green/public space
- consideration of key construction and maintenance issues.

At this stage, it is crucial to secure a complete understanding as to who will be the long-term owner of the drainage assets (some assets are likely to remain in private ownership, while others may be adopted by public bodies) and who will operate and maintain the assets. This will dictate any site-specific adoption criteria and also the required processes set by the relevant drainage adoption body.

Where the proposed system has operational requirements (eg pumping), the operation protocols and emergency procedures will need evaluating and agreeing with the adoption body.

Even at early stages in the design, it is important to ensure that long-term maintenance is as cost-effective as possible, and that any future owner will have easy access to all parts of the drainage system that may require future maintenance, and any equipment and skills required to undertake the work.

Options for the disposal of waste (arising from sedimentation and vegetation management) should also be considered.

▶ Guidance on assessing potential costs and benefits of different SuDS options is provided in **Chapter 35**.

▶ Guidance on operation and maintenance requirements is provided in **Chapter 32**.

▶ Guidance on waste management requirements is provided in **Chapter 33**.

▶ Guidance on community engagement strategies is provided in **Chapter 34**.

7.6 STAGE 3: OUTLINE DESIGN

The third stage of the SuDS design is the outline design, which should be developed alongside the agreed layout and design of the development, and landscape and building characteristics. Key steps in outline design are shown in **Figure 7.11** and described in the following sections.

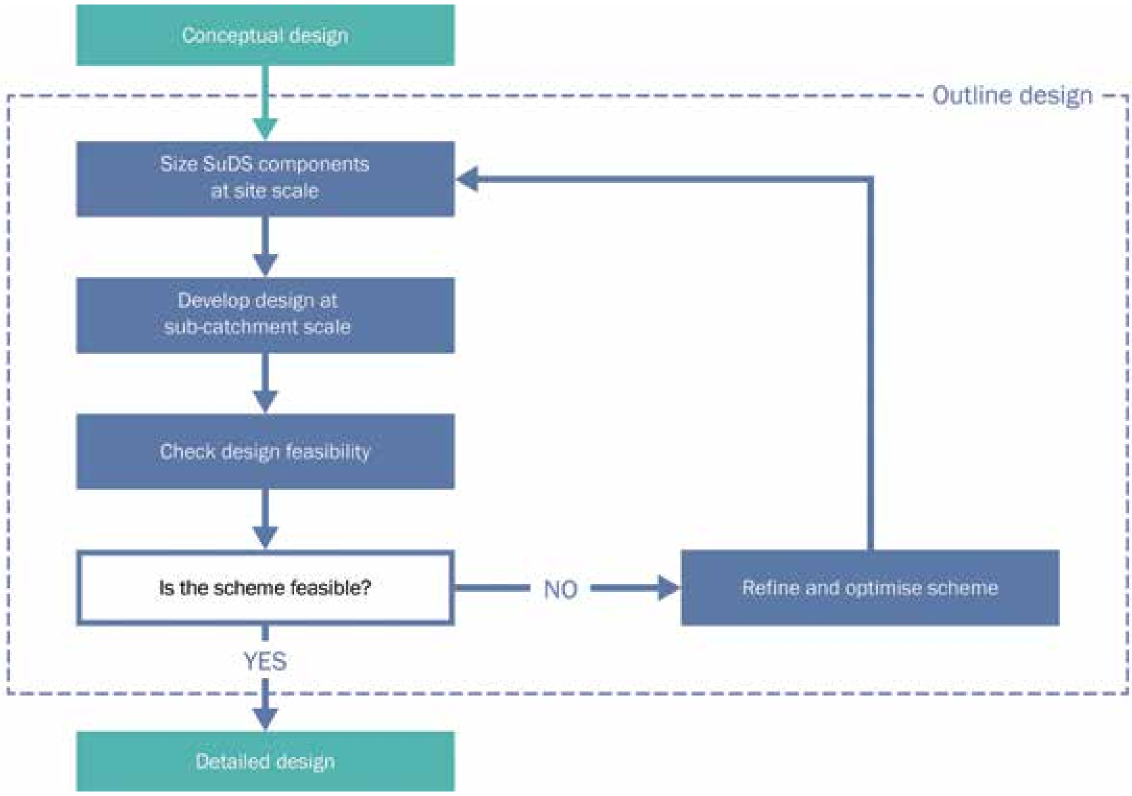

Figure 7.11 The outline design process

Outline designs will usually be required where outline planning permission is sought. Where only a full planning permission is sought, the stages involved here will still be required, but should be incorporated into the detailed design stage (Section 7.8).

7.6.1 Size SuDS components at site scale

In order to further develop the SuDS design, estimates will be required for the following:

- the greenfield (and/or agreed proportion of previously developed) runoff rates, to which the runoff from the site will need to be controlled
- likely runoff rates from the developed sub-catchments (including any climate change and urban creep provisions)
- infiltration capacities where infiltration components are proposed
- demand for non-potable water where rainwater harvesting components are proposed
- the remaining difference in runoff volume between the development runoff volume and the greenfield (or other agreed) runoff volume for a specified large event.

The required attenuation storage volume will be dependent on the increase in runoff rate because of the development, and the design rainfall event characteristics.

This will allow initial sizing calculations to be done of the:

- volumes assumed to be harvested for different return periods
- volumes assumed to be infiltrated for different return periods
- total attenuation storage volumes required for the site for different return periods
- extra storage volumes likely to be required for volume control for the 1:100 year event (ie Long-Term Storage).

The design process is set out in Figure 7.11. Detailed guidance on each of the steps is presented in Chapters 24 and 25.

- The design criteria and standards for water quantity are presented in Chapter 3.
- Guidance on methods for estimating greenfield runoff rates is presented in Section 24.3.
- Guidance on methods for estimating previously developed site runoff rates is presented in Section 24.5).
- Guidance on methods for estimating runoff rates from the developed site surfaces is presented in Section 24.6.
- Guidance on designing for climate resilience is provided in Section 3.2.7.
- Guidance on climate change factors and urban creep factors is provided in Section 24.7.
- Guidance on infiltration design is provided in Chapter 25.
- Guidance on the design of RWH systems is provided in Chapter 11.
- Guidance on attenuation storage design is presented in Section 24.9.
- Guidance on Long-Term Storage design is presented in Section 24.10.

7.6.2 Develop design at sub-catchment scale

At this stage, the individual SuDS components should be sized, and their designs refined. Any assumptions made at conceptual design stage, such as infiltration capacities, groundwater levels and existing sewerage infrastructure and capacities, should be confirmed, using robust evaluation methods.

Required storage volumes should be distributed between sub-catchments (where appropriate), estimates should be made of required conveyance and exceedance flow rates and checks should be made that proposed treatment components are adequate. Any required flow control components should be defined and scoped. This process is set out in Figure 7.12.

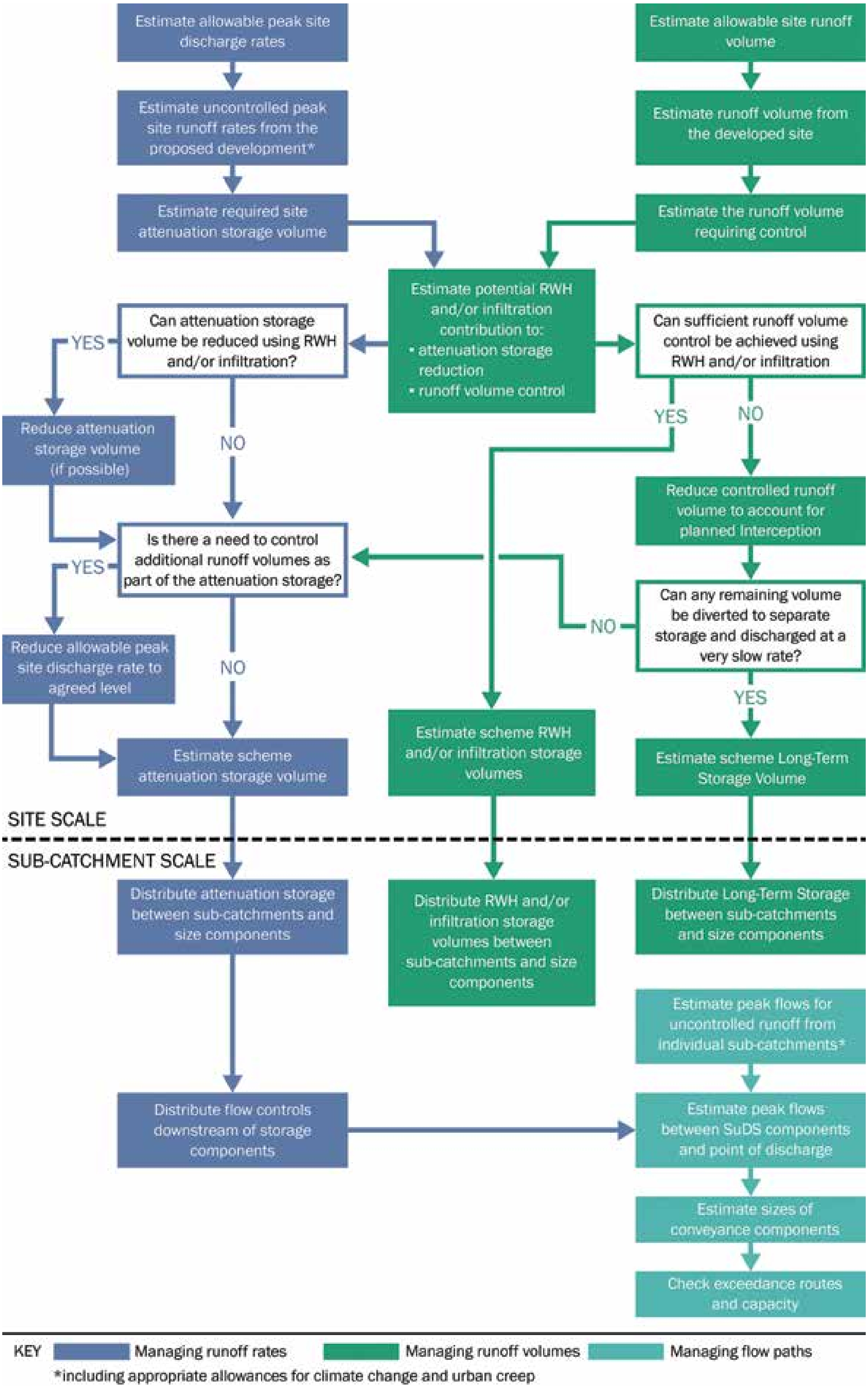

Figure 7.12 Site and sub-catchment scale component sizing for outline design

- Guidance on methods conveyance system design and exceedance design is provided in **Sections 24.11 and 24.12**.
- Guidance on designing for treatment is provided in **Chapter 26**.
- Guidance on component sizing for water quantity and water quality management is provided in **Chapters 11–23**.
- Guidance on infiltration testing and design is provided in **Chapter 25**.
- Guidance on flow control component design is provided in **Chapter 28**.

7.6.3 Check design feasibility

The constructability and maintainability of the proposed SuDS scheme should be given full consideration, and initial construction and maintenance strategies developed for consideration by stakeholders.

A preliminary health and safety risk assessment should be developed. SuDS designs will require consideration as part of any CDM risk assessment process.

Any requirements of the drainage approving body and other engaged stakeholders regarding design detailing should be evaluated at this stage.

The costs of the scheme should be given full consideration and agreed with scheme funders, and likely long-term operation and maintenance costs should be approved by the drainage adoption body before final design. Where scheme investment is driven by benefits delivered by the scheme, benefit quantification should also be undertaken.

- Guidance on generic SuDS construction requirements is provided in **Chapter 31**, with component specific detail contained within **Chapters 11–23**
- Guidance on generic SuDS maintenance requirements is provided in **Chapter 32**, with component specific detail contained within **Chapters 11–23**.
- Guidance on designing safe surface water management systems is provided in **Section 5.2.4**
- Guidance on health and safety is provided in **Chapter 36**, and the health and safety checklist is provided in **Appendix B** (**Section B.3, Table B.5**).
- Guidance on costing designs is provided in **Chapter 35**.

7.6.4 Outline design: Reporting

Reporting at this stage should be sufficient to support outline planning applications, and should include preliminary sizing for each component and exceedance flow management route. The outline design statement should establish:

- points of discharge of the surface water runoff from the site
- the extent to which each of the design criteria (quantity, quality, amenity and biodiversity) will be delivered by the SuDS design, and the impact of any stakeholder engagement undertaken during the design process
- statements regarding how each of the criteria will be delivered by the system
- a description and evaluation of proposed Interception measures for all impermeable areas
- a suitable SuDS Management Train(s) for all sub-catchments that delivers appropriate treatment
- infiltration tests (where practical – or other infiltration assessments based on desk studies) and approximate infiltration designs (where relevant)
- approximate attenuation and Long-Term Storage volumes and appropriate flow control systems to manage flows and volumes for different return periods, including design exceedance events

- initial health and safety risk assessment (as part of CDM process)
- plan and elevation drawings of the proposed scheme
- an operation and maintenance plan (that includes waste disposal).

A more formal list of requirements might be set by a drainage approving body at outline planning stage.

▶ An example list of requirements for reporting is set out in **Appendix B** (**Section B.1.2, Table B.2**).

7.7 STAGE 4: DETAILED DESIGN

The fourth stage of the SuDS design is the detailed design, which should refine the SuDS design in line with the final development design, and determine sizing and detailing for final drawings and documentation to be submitted for planning approval, drainage approval and to contractors for costing purposes.

Where the outline design stage is omitted, the design steps described in **Section 7.7** should be incorporated as part of the detailed design stage.

The design should be refined and finalised following the process set out in **Figure 7.13**.

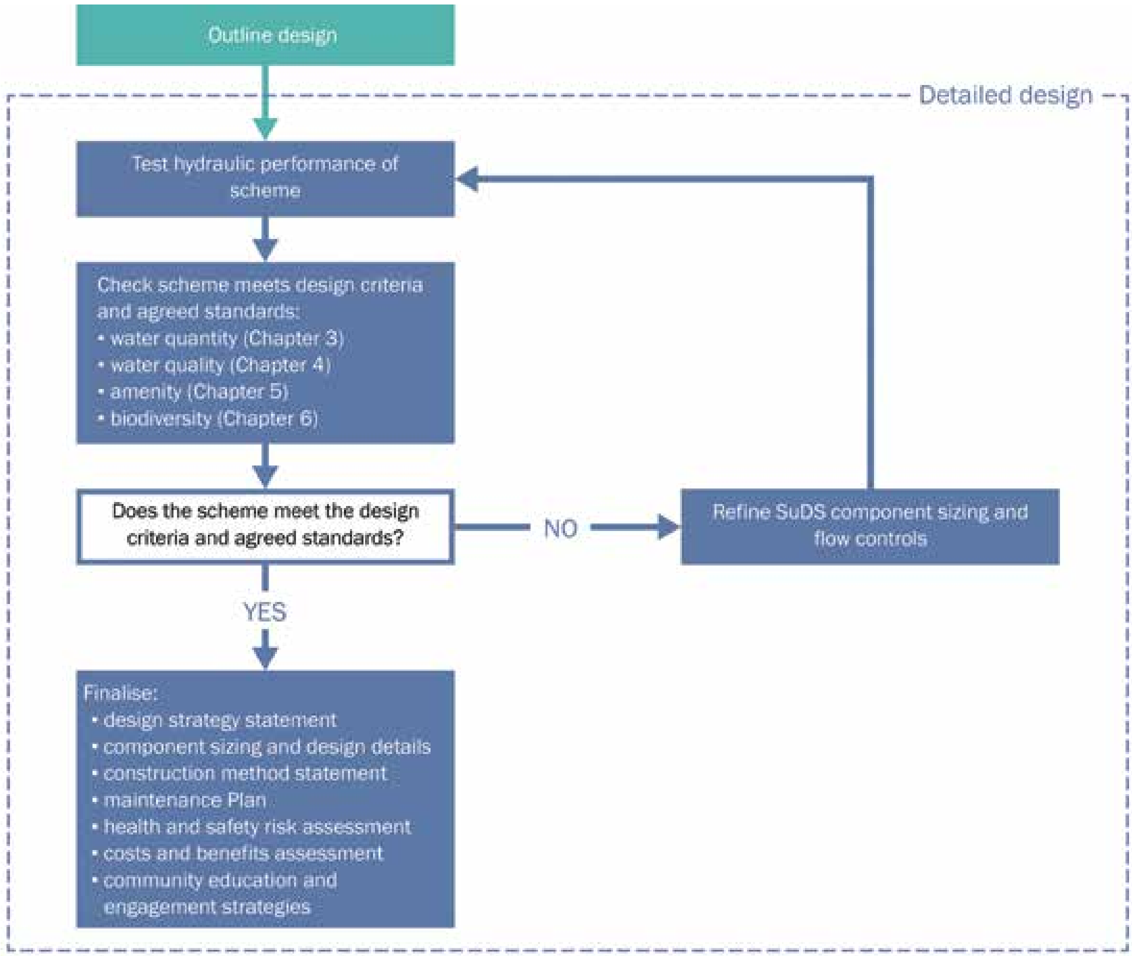

Figure 7.13 The detailed design process

7.7.1 Test hydraulic performance of scheme

The scheme should be tested hydraulically to identify the worst case hydraulic condition for each component for all design return periods. This should be undertaken using either design storms or time series rainfall (TSR) analysis.

The hydraulic performance of the system should then be optimised to make sure that all storage and conveyance areas are used as effectively as possible during design rainfall events. Drainage simulation models can be used where appropriate.

Consideration should be given to the extent to which the SuDS components should function during flood events affecting the receiving surface waters.

Account should also be taken of any overland flow routes across the site from external areas or other external flood sources. Such flows will either need to be routed around the site or conveyed across the site, either in exceedance routes or within the SuDS components themselves. The likely rates and volumes of these extra flows will need to be accounted for in the system design so that people and property on the site are not put at risk.

Exceedance routes should be evaluated and designed where required, ensuring appropriate levels of freeboard between extreme flood levels and building floor levels

- Guidance on rainfall characteristics is provided in **Section 24.2.3**
- Guidance on Interception, attenuation and Long-Term Storage design, conveyance and exceedance route sizing is presented in **Sections 24.8 to 24.12**.
- Guidance on infiltration design is provided in **Chapter 25**.
- Guidance on the design of RWH systems is provided in **Chapter 11**.
- Guidance on design of inlets, outlets and flow control systems is provided in **Chapter 28**.

7.7.2 Check scheme meets design criteria and agreed standards

Checks should be made that the final scheme meets all of the design criteria established for the site (**Section 7.6.2**). At this stage, it is likely that the main checks will be that the system meets the agreed standards for quantity and quality, that:

- Interception is delivered for all hard areas
- peak rates of runoff for low return period events are adequately controlled
- peak rates of runoff for high return period events (including appropriate climate change and urban creep factors) are adequately controlled
- volumes of runoff for high return period events are adequately controlled
- high return period events (including appropriate climate change and urban creep factors) do not pose an unacceptable risk to people or property, as a result of the development
- the flow velocities and depths for regular events allow effective treatment to be delivered by components for which treatment performance is assumed.

The performance of the system with respect to the remaining water quantity and water quality criteria, and the amenity and biodiversity criteria is unlikely to change materially at this stage in the process. However if, because of non-compliance with the above standards, a decision is made that a component should change fundamentally (eg a surface component has to become a subsurface component), then a review of performance to the full suite of criteria will be required.

Indicators are likely to be a useful way of assessing the performance of the scheme to agreed criteria and where these have been established early in the design process – they can potentially form a framework for the assessment process (eg *"the proportion of the scheme that is on or near the surface"* is likely to be a useful indicator of the extent to which the scheme might deliver a number of the water quality, amenity and biodiversity criteria).

- ▶ Example indicators for water quantity, water quality, amenity and biodiversity criteria are presented in **Chapters 3–6**.

7.7.3 Refine SuDS component sizing and flow controls

Where the agreed standards (described in **Section 7.8.2**) are not met satisfactorily, the design will need to be revisited, and amendments made to component sizing and/or flow controls. The hydraulic testing will then need to be undertaken again. This process will usually occur iteratively until a satisfactory solution has been identified.

- ▶ Guidance on Interception, attenuation and Long-Term Storage design, conveyance and exceedance route sizing is presented in **Sections 24.8 to 24.12**.
- ▶ Guidance on infiltration design is provided in **Chapter 25**.
- ▶ Guidance on the sizing of RWH systems is provided in **Chapter 11**.
- ▶ Guidance on treatment design is presented in **Chapter 26**.
- ▶ Guidance on sizing of inlets, outlets and flow control systems is provided in **Chapter 28**.

7.7.4 Finalise design

The final design should be refined, taking costs and benefits into account, together with any health and safety risk assessment (required as part of CDM), constructability and maintainability considerations.

Individual SuDS components should be finalised and detailed following the guidance within the technical component chapters of this manual and/or appropriate manufacturer literature.

Specifications will need to be prepared for all the materials used in the design, and for the construction and landscaping works, together with full construction method statements and Maintenance Plans.

Community education and engagement strategies for the completed system should be developed. In some cases these will evolve from community input provided during earlier design stages.

A design statement should be prepared, which includes a description of each of the system criteria and standards, and the approaches through which these criteria and standards have been met.

- ▶ Guidance on component design is provided in **Chapters 11–23**.
- ▶ Guidance on design of inlets, outlets and flow control systems is provided in **Chapter 28**.
- ▶ Guidance on construction is provided in **Chapter 31**.
- ▶ Guidance on maintenance of SuDS is provided in **Chapter 32**.
- ▶ Guidance on waste management is provided in **Chapter 33**.
- ▶ Guidance on community environmental learning is provided in **Section 5.2.7**.
- ▶ Guidance on community engagement is provided in **Chapter 34**.

7.7.5 Detailed design: Reporting

At this stage, reporting should include the final detailed design and specification for the SuDS scheme sufficient to support a full planning application, including:

- infiltration and geotechnical test results and evaluation

- design methods used (eg for greenfield or previously developed runoff rate assessments) and justification
- full calculations for the overall scheme and individual components
- justification of any non-compliance to national or local standards
- detailed design drawings
- materials specifications
- landscape specifications
- construction method statement
- scheme Maintenance Plan (including costs)
- final design statement.

A more formal list of requirements might be set by a drainage approving body at full planning application stage.

▶ An example list of requirements for reporting is set out in **Appendix B** (**Section B.1.3, Table B.3**).

7.8 REFERENCES

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Image courtesy Robert Bray Associates

8 DESIGNING FOR SPECIFIC SITE CONDITIONS

Contents

Chapter
08

Designing for specific site conditions

This chapter demonstrates how SuDS can be successfully designed for sites with conditions that are often considered challenging.

Guidance on designing SuDS for roads and highways can be found in Chapter 9.

▶ *Guidance on designing SuDS for roads and highways can be found in Chapter 9.*

▶ *Discussion on integrating SuDS into high density urban areas can be found in Chapter 10.*

▶ *Guidance on dealing with infiltration design challenges (eg high variability in infiltration rates and low infiltration rates) is set out in Chapter 25.*

8.1 INTRODUCTION

SuDS can be delivered on all sites, but most sites will pose challenges of one sort or another in relation to the selection and integration of effective SuDS components. Most of these will be relatively straightforward to solve, using engineering and landscape best practice. However, there are a few challenges that have mistakenly been raised as potential reasons why SuDS cannot be used and these are addressed here.

This chapter demonstrates, with examples, how SuDS can be integrated into sites that have:

- contaminated soils or groundwater below the site
- high groundwater levels
- steep slopes
- no gradient or very shallow slopes
- underlying rocks or soils that are prone to instability, that is, slope stability, dissolution or other voids (eg old mine workings)
- sites with very deep backfill (eg infilled open cast sites, old landfill sites)
- sites with open space in floodplain zones.

8.2 CONTAMINATED SOILS OR GROUNDWATER BELOW THE SITE

8.2.1 The challenges

When designing a surface water management system for a site that overlies contaminated soil or groundwater, the following issues should be considered within the design process:

1. The presence of contamination in the ground may prevent the use of infiltration. This is because water soaking through the ground can mobilise contamination and thereby pollute groundwater.
2. Contaminated groundwater may flow into the SuDS. This would only occur if unlined conveyance and/or attenuation components are located below maximum likely groundwater levels.

3 Contamination may have an adverse effect on materials used in the construction of the SuDS.

4 Inappropriate design of the SuDS could compromise the remediation system provided to protect residents from any contamination that is left in the ground. One example is where SuDS are designed to extend below any capping layer provided to prevent contact with contamination.

5 Excavation and disposal of contaminated soils in order to construct drainage systems is expensive.

The above issues are not valid reasons for not using SuDS on sites affected by contamination. They can be overcome by careful planning, communication, risk assessment and design detailing. It is generally appropriate to seek advice from a geo-environmental professional with experience in contaminated land issues, as early as possible in the development planning process, so that drainage and any remediation strategies can be integrated, and a cost-effective solution developed.

▶ Guidance on planting in contaminated soils is provided in **Chapter 29**.

8.2.2 Preventing the flow of contaminated groundwater into the SuDS

Impermeable barriers can be used to prevent contaminated groundwater flowing into any SuDS component. However, it is preferable to construct the SuDS component above the groundwater table to minimise the risk of groundwater entering it, rather than relying on liners. The minimum distance between the maximum likely groundwater table and the base of the SuDS should be based on a detailed groundwater risk assessment, although 1 m of unsaturated soil is often sufficient, unless specific risks exist.

8.2.3 Preventing damage to SuDS material from contamination

The issues for the construction of SuDS are no different from any other construction in contaminated ground, including piped drainage. An assessment of the impact on any materials likely to be in contact with contamination should be undertaken to make sure that the materials will be durable in the anticipated exposure conditions. Guidance is provided in Privett *et al* (1996), EA (2001) and Paul (1994).

8.2.4 Protecting the contaminated land remediation system

When designing SuDS on contaminated sites, it is important to fully consider the planned site remediation strategy. If possible, the SuDS design and the design of the remediation strategy should be integrated, to maximise efficiencies and opportunities and to minimise costs. Clear communication between all parties is paramount for the success of these schemes.

If a capping layer is to be provided, it will often only be constructed below gardens and landscaped areas. Hard areas such as parking are usually considered to be an effective capping layer themselves, without any extra provision (although this is not the case for pervious pavements). Capping layers can be extended below SuDS components, such as ponds or swales as shown in **Figure 8.1**.

If contamination is to be removed or reduced either by excavation or *in situ* remediation, this may mean that SuDS can be designed as for any uncontaminated site. Again close collaboration with the remediation designers is necessary.

8.2.5 Minimising the excavation and disposal of contaminated soils

The use of well-designed, shallow SuDS can minimise excavation and disposal when compared to piped drainage and deep tanks. They can also reduce the risk of creating preferential pathways for vapour and gas migration via pipes and backfill. SuDS that are shallow and on the surface usually also offer significant advantages with respect to the health and safety of construction workers, because contact with contaminated soils can be minimised.

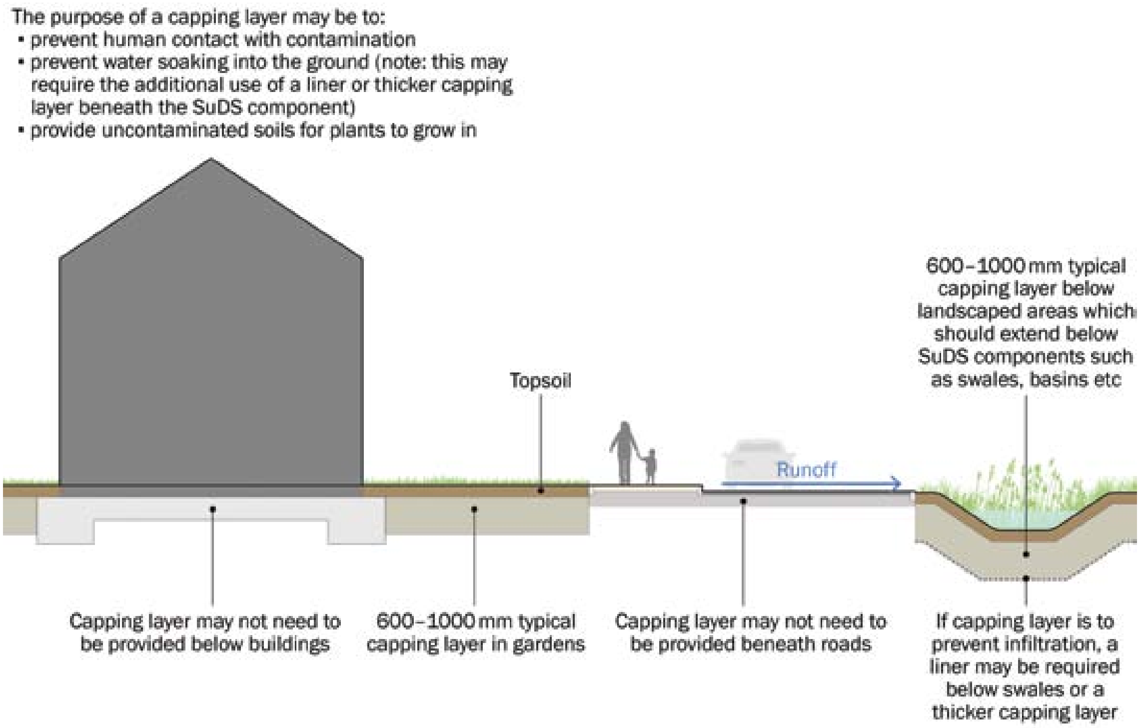


Figure 8.1 Contaminated land and SuDS: typical capping layers

8.2.6 The use of infiltration on contaminated land sites

When considering the suitability of infiltration for a contaminated land site, the specific location and depth of contamination should be evaluated. This will clarify whether infiltration can potentially be used in some areas and not others, or if infiltration is not suitable for the site at all. A risk assessment and assessment of the leaching potential of contamination should be undertaken by a contaminated land specialist, to determine whether pollution will be mobilised. If infiltration is not suitable, then SuDS components should be designed not to allow infiltration.

Figure 8.2 Unlined permeable pavement on a contaminated site, Stamford, Lincolnshire (courtesy EPG Limited)

The permeable pavement for the high-density development in Figure 8.2 is constructed on a small, constrained brownfield (previously developed) site where there was some hydrocarbon contamination from previous industrial use. The risk assessment together with the assessment of leaching potential determined that limited infiltration (to provide Interception) would not be a risk to groundwater.

Depending on the depth, infiltration systems can potentially be located below any contamination so that the infiltrating water does not come into contact with the contamination. Contaminated soils can also be removed from the immediate area around soakaways. These solutions are illustrated in Figure 8.3. The use of vertical geomembranes placed around the edge of the excavation could also be considered to minimise the risk of horizontal migration of the infiltrating water into the contaminated soil.

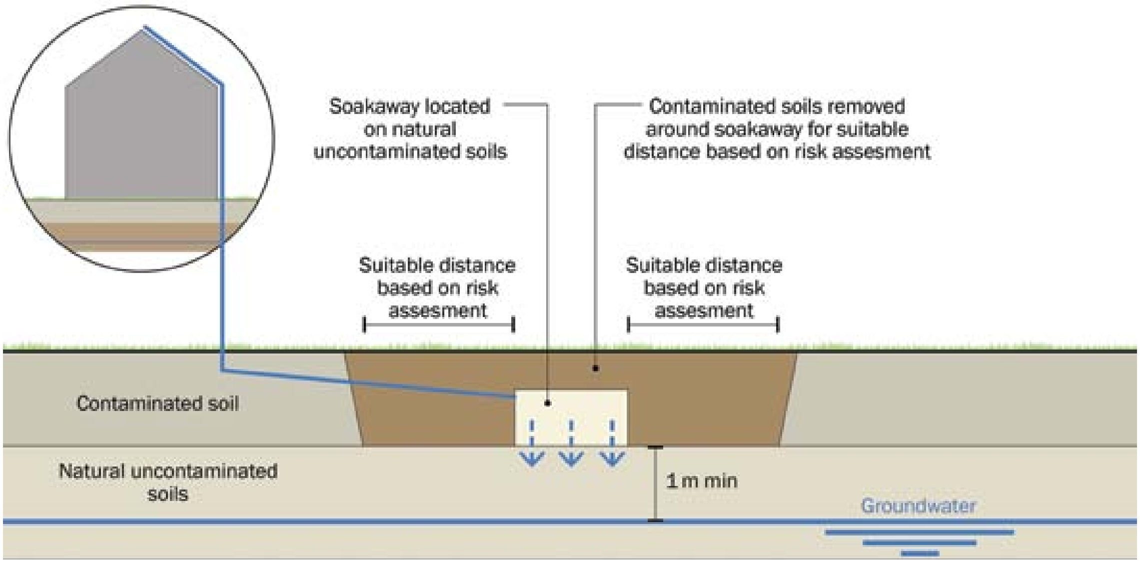


Figure 8.3 Locating infiltration systems beneath layers of contamination and/or removal of contaminated soils from around soakaways

If infiltration is not considered appropriate for the site, following a risk assessment, drainage systems can be lined to prevent water soaking into the ground and connected to a suitable outfall system. While not providing infiltration, and reducing the potential for Interception, it can still attenuate flows. An example of a lined permeable pavement constructed over a former landfill site is shown in **Figure 8.4**.

It is important to consider the impact of contamination on the liner, for both geosynthetic and mineral (eg clay) liners.

Figure 8.4 Lined permeable pavement constructed over a former landfill site, Portsmouth (courtesy EPG Limited)

If large expanses of a site are covered by liners (eg a large expanse of lined permeable pavement in a park-and-ride), then the impact of effectively sealing the site surface may need to be considered where there is gas or vapour contamination in the ground. If ground gas or vapour is migrating through the surface of the undeveloped site, sealing the surface could potentially force gas to migrate sideways, although this can be prevented by providing a suitable venting system. Small areas of impermeable lining (ie covering a small proportion of the surface) are not likely to have a great effect on gas and vapour migration horizontally.

8.3 HIGH GROUNDWATER LEVELS BELOW THE SITE

8.3.1 The challenges

When designing a surface water management system for a site that overlies high groundwater levels (ie maximum likely groundwater levels are within 1 m of the base of the SuDS component – see **Section 25.2.2**), the following challenges should be considered within the design process:

- The use of infiltration may not be suitable due to reduced hydraulic and treatment capacity.
- If SuDS are constructed below the maximum likely groundwater level, then groundwater can potentially enter the SuDS component and reduce the storage capacity.

- Flotation and structural design risks to storage structures or impermeable liners can occur because of the extra loads imposed by the groundwater and the buoyancy of the tanks or liner.

One example of SuDS on a site with high groundwater levels is the Henry Box site in Witney, Oxfordshire. On this site, shallow source control methods using a combination of swales and kerb drains was used to manage surface water (**Figure 8.5**). Groundwater was 400 mm to 700 mm below the surface of the site, and ground levels could not be raised as part of the development.

Figure 8.5 Shallow swale on a site with shallow groundwater, Witney, Oxfordshire (courtesy EPG Limited)

8.3.2 The use of infiltration where groundwater levels are high

Infiltration may not be suitable where there is not an adequate depth of unsaturated soils (ie greater than 1 m) between the infiltration surface and the groundwater. Any assumption of pollution protection within the unsaturated soil layer will also be invalidated. Contaminated surface water runoff can potentially directly pollute groundwater if the groundwater is hydraulically linked to water within the SuDS.

Depending on the depth of groundwater below the site it may be possible to use shallow infiltration basins or permeable pavements. On some sites careful use of land raising with suitable fill materials may also be an option, although this will require advice from a ground engineering specialist, to ensure that the infiltration capacity and risk of settlement or instability is acceptable.

Where infiltration into sites with shallow groundwater tables is proposed, the impact of recharge in thin aquifers leading to groundwater mounding (even under average conditions) should be considered. This risk is minimised by using planar infiltration systems such as discharges from below a pervious surface.

The impact of fluvial flood events on groundwater levels should also be considered, as there may be impacts even if the site is outside the fluvial flood plain.

8.3.3 Reduced system capacity resulting from high groundwater levels

It is important to keep storage and conveyance systems above maximum likely groundwater levels, wherever possible. This will avoid difficulties during construction caused by water flows into excavations and will ensure that the hydraulic and treatment capacity of the SuDS component is retained at all times.

It is very difficult to completely seal a geomembrane around a geocellular tank or permeable pavement, and any water ingress can impact on the available internal hydraulic storage capacity. This is recognised in the landfill industry where lining systems rely on multiple layers to form an effective containment system. Even in landfill sites with highly regulated installation and quality assurance procedures it is still recognised that holes in a liner can occur, mainly due to defects in jointing or from post-installation damage (Privett *et al,* 1996). **Table 8.1** provides information in the leakage rates from various defects in liners. This shows how important it is that robust membranes are used to line tanks, and that they are integrity tested after installation.

TABLE 8.1 **Calculated flow rates through a geomembrane liner with 0.3 m of water ponded on the liner (after USEPA, 1991)**

Size of defect (mm²)	Number of defects per hectare	Leakage rate (l/ha/day)
0	0	0.09*
10	2.5	3140
10	75	94 300
100	2.5	31 400
100	75	943 000
1000	2.5	314 000

Note

* advection flow through intact geomembrane material.

Information on integrity testing of geomembranes used in gas protection systems in buildings is provided in Mallett *et al* (2014). The methods of integrity testing and advice on visual inspections is applicable to membranes used in SuDS, and indeed some of the methods described in the report have been used to test membranes installed around geocellular tanks. Testing may be required at different times of installation (eg when the membrane is laid out over the base, and then later when the geocellular units are installed and the membrane is wrapped over the sides and top).

Comparison of leakage rates with the allowed discharge from a tank show that if the leakage rate is more than about 5% of the allowed discharge rate then the hydraulic design capability of the tank will be compromised. The use of tanks with membranes below groundwater is not recommended. It should also be noted that surface linear channel systems cannot be assumed to be completely sealed and, if they extend below the groundwater table, then water will leak into them.

8.3.4 Flotation and structural risks from high groundwater levels

It is important to avoid locating storage tanks or lined sub-base systems below the maximum likely groundwater level, if at all possible. There are two reasons for this:

- The lateral loads on the side of tanks increase significantly if groundwater is applying pressure to the side of the tank and will therefore impact on the structural design of the system.
- Buoyancy of the tank or lined sub-base can cause uplift failure of the system. Flotation should be prevented by having sufficient counter force, which will be derived from the self-weight of the tank construction and the weight of permanent backfill over the top of the tank. Shallow 150 mm deep attenuation tanks have been successfully used below concrete slabs where groundwater was very close to the surface. In some cases where it has not been possible to resist uplift forces by dead weight alone, extra resistance has been provided using anchorage systems.

8.4 SLOPING SITES

8.4.1 The challenges

When designing a surface water management system for a steeply sloping site (usually greater than 3% to 5%), the following issues should be considered within the design process:

- the effective utilisation of storage capacity within SuDS components
- the likely velocities in swales and basins due to the steep gradients (which affects scour, erosion and resuspension of pollutants, as well as health and safety)
- the risks of infiltrating water reappearing as spring lines further down a slope

8.4.2 Hydraulic capacity of SuDS components on sloping sites and control of conveyance velocities

Available storage capacity can be reduced where SuDS components are implemented on sloping sites. However, there is usually a need to terrace the site to fit in the proposed development. Roads will normally be designed to run at shallow slopes across contours. This allows space to be found between the contours into which SuDS can fit.

A sloping site (as shown in **Figures 8.6 and 8.7**) can have opportunities for attenuation storage areas. Terracing for parking areas provides opportunities for pervious pavements to store water. Basins can also be provided on terraces formed to deliver open space for the development. If space is limited, geocellular sub-base replacement can be used below such basins to drain larger areas by increasing the available storage. Successful SuDS design on sloping sites usually involves splitting the runoff catchment into small, manageable sub-catchments, and looking for all the potential opportunities for runoff conveyance and storage.

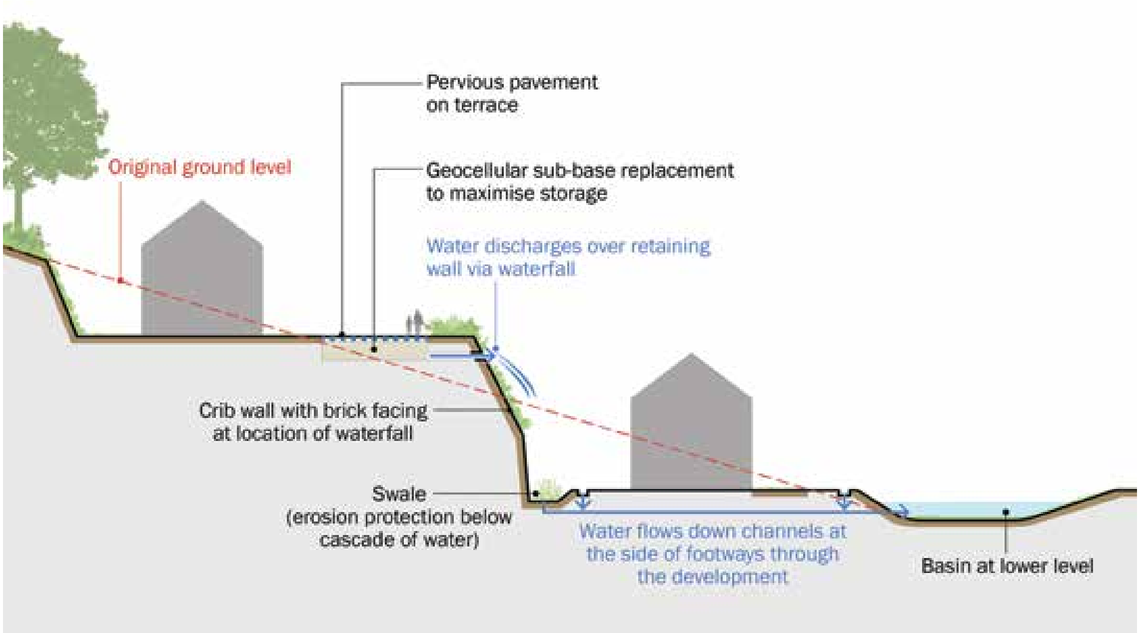


Figure 8.6 Cross-section showing example SuDS on a sloping site

Figure 8.7 Retaining wall and waterfall (a) and planted pool with overflow to play basin (b), Springhill Co-housing, Stroud (courtesy Robert Bray Associates)

It is possible to slow down the flow of water and increase storage on sloping sites by using check dams in swales or in storage layers, for example below permeable pavements. Examples of check dams in swales are shown in **Figures 8.8a to 8.8b**. Check dams can also be combined with road or pedestrian crossings as shown in **Figure 8.8c**. Guidance on check dams in swales and pervious pavements is provided in **Chapters 17 and 20** respectively.

Figure 8.8a Check dams in a swale, Oxfordshire (courtesy EPG Limited)

Figure 8.8b Check dam in a swale during construction, Lincoln (courtesy Lincolnshire County Council)

Figure 8.8c Check dams can be combined with road/pedestrian crossings, Upton, Northamptonshire (courtesy EPG Limited)

8.4.3 Risks from infiltration

Whether or not infiltration systems pose a problem on steeply sloping sites will depend on the geology below the site. The impact of using infiltration drainage on sloping sites should be assessed by a competent geotechnical engineer or engineering geologist.

It is possible that infiltrating water may cause seepages out of the slope at a lower level, which could cause flooding or instability. Care also has to be taken where water is infiltrating close to retaining walls, because water could issue from the face of the wall, or it could increase the overturning pressure on it and cause it to fail.

A single small soakaway may not have any significant effect on groundwater flows at lower levels, but the combined effect of many such components could be significant. The geology and slope angle together with the likely volume of water that is infiltrated will determine the extent of any potential risk. Layered strata with impermeable soils or rocks will present the greatest risk of spring lines developing due to infiltration drainage higher up a slope, as shown in **Figure 8.9**.

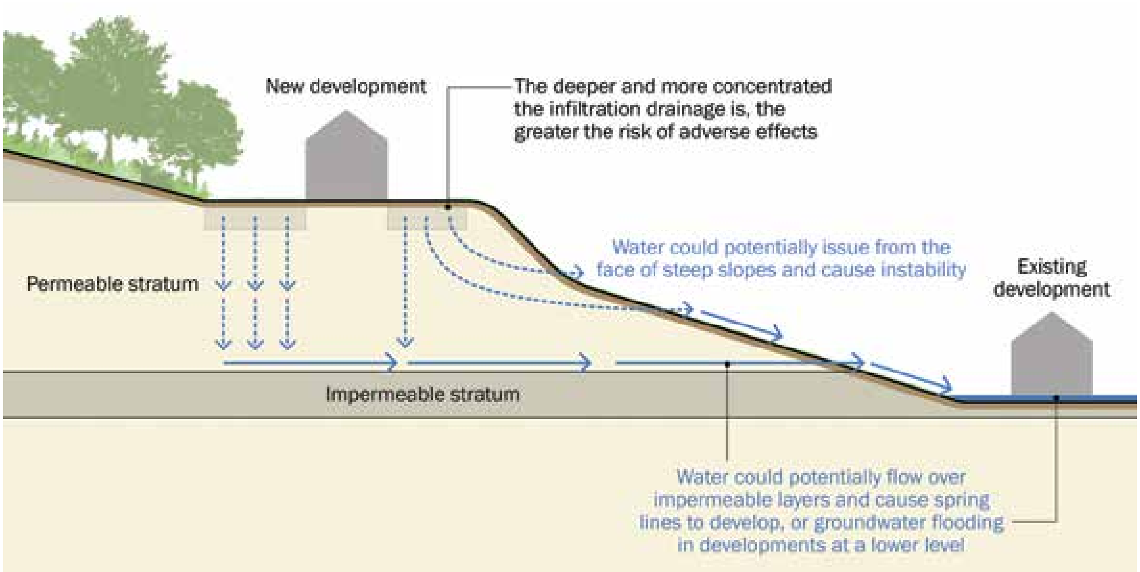


Figure 8.9 Impact of geology on water flows from infiltration drainage on sloping sites

8.5 VERY FLAT SITES

8.5.1 The challenges

When designing a surface water management system for a very flat site, the following challenges should be considered within the design process:

- achieving sufficient gradients to drain runoff effectively
- difficulty in meeting outlet levels to existing watercourses or sewers
- impacts of downstream water levels on drainage system performance.

8.5.2 Sufficiency of hydraulic gradients for effective drainage

On very flat sites, it is often not possible to construct piped drainage systems with sufficient falls to achieve minimum self-cleansing velocities. So using shallow SuDS components such as swales, pervious pavements or high capacity linear drainage channels is an advantage in these situations. Good SuDS design should aim to divide the site into small sub-catchments and provide local combined storage and conveyance components. The hydraulic head that develops as water flows into and builds up in the system will then cause water to flow out of the system.

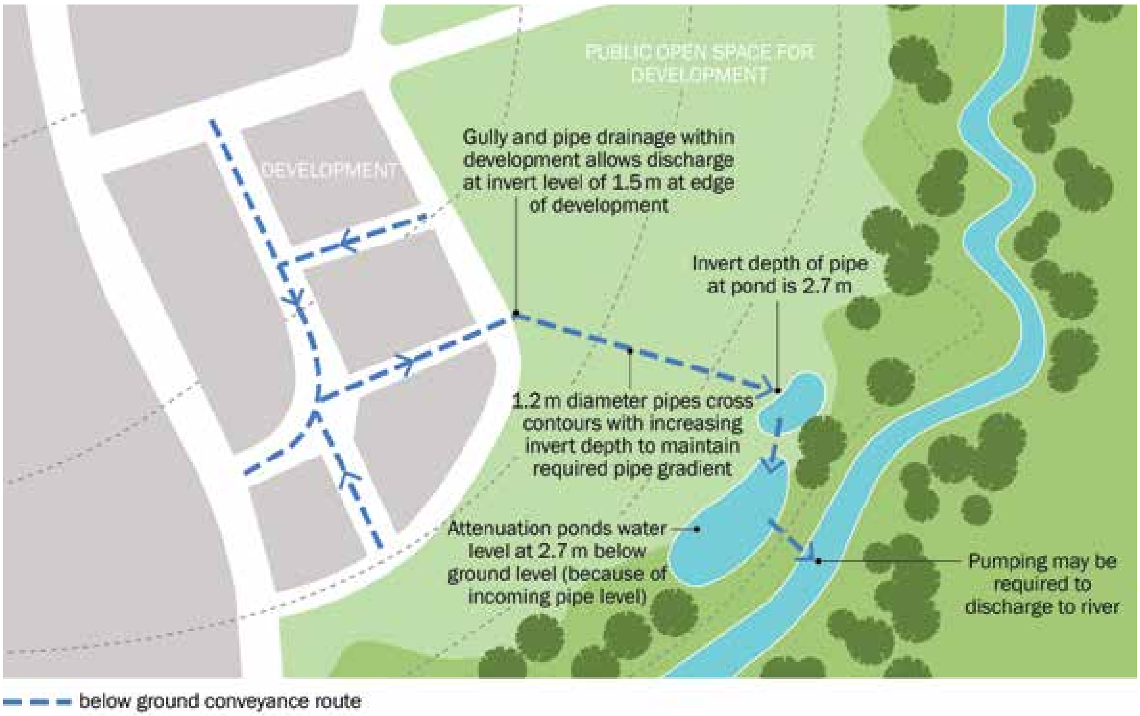
This is a common issue in low-lying coastal (internal drainage board) areas where piped drainage and the necessary cover often compromise the ability to achieve a suitable outfall. A common solution is to provide extensions of rhyne systems and provide storage volume within an on-site swale/rhyne system embedded throughout the development.

On flat sites, or indeed any site where a storage tank or layer has a flat base, ponding of water may occur in the base of the storage. If this occurs in systems that are not lined (where the soils are impermeable and do not therefore allow infiltration), the water could be in contact with the underlying soils for a significant length of time and could ultimately reduce the strength of the soil. If possible, a slight fall on any subgrade exposed to water is preferred, to avoid ponding of water. If this cannot be provided, then the reduction in strength due to waterlogging should be taken into account in the structural design of tanks or pervious pavements.

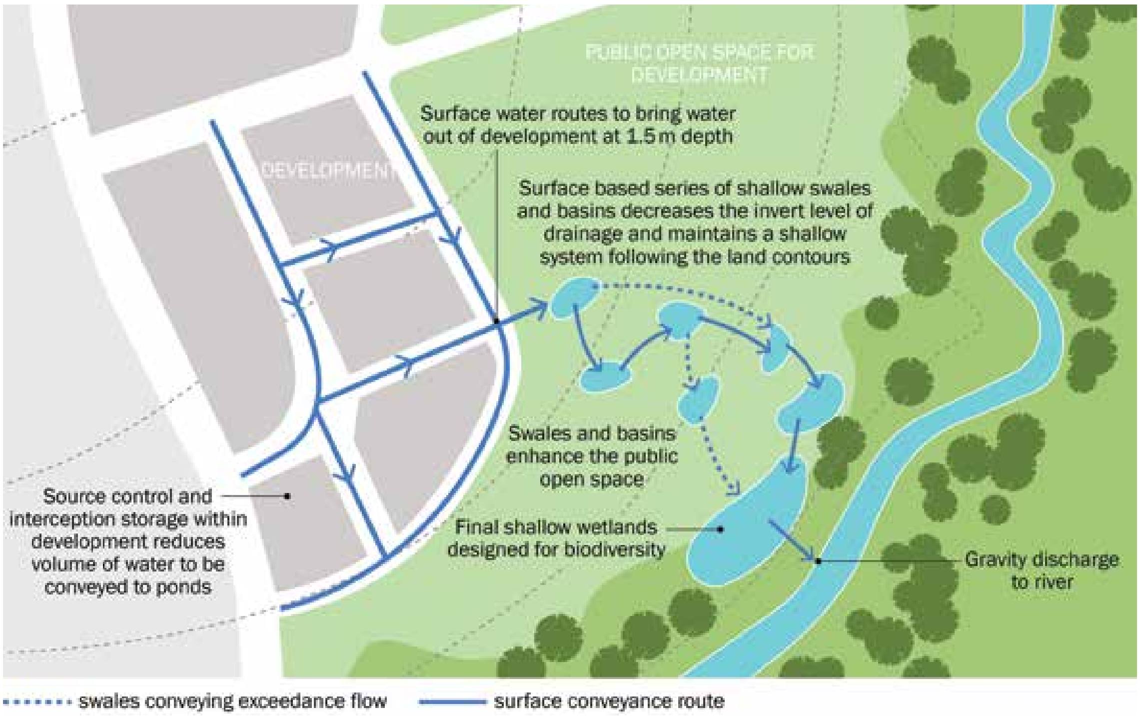
8.5.3 Meeting minimum outlet levels

A normal drainage system will often end up being fairly deep. Even using shallow SuDS components, the end of the surface water drainage system may still end up below the minimum allowable outfall level. In such cases, a pumping station will be necessary. Several SuDS schemes have included pumping stations, but they should be a last resort and only allowable in situations where guaranteed maintenance of the pumps can be ensured.

Figure 8.10 demonstrates the advantages of SuDS in meeting minimum outfall level constraints.



a Piped system



b SuDS scheme

Figure 8.10 Example comparison of piped drainage system to a SuDS scheme

8.6 SITES WITH POTENTIALLY UNSTABLE SUBSURFACE ROCKS OR SOIL WORKINGS

8.6.1 The challenges

When designing a surface water management system on a site that may be prone to subsurface soil or rock instability, the following issues should be considered within the design process:

- Water infiltration into the ground can cause instability in poorly consolidated soils, because the water can wash out the soil or cause it to compact. Also, rocks such as chalk may slowly dissolve over time.
- Water from infiltration systems can cause slope or retaining wall failure, because water pressure may increase in the soil behind the slope or wall.

Guidance on areas of potential surface geology instability can be found via BGS infiltration maps: **http://tinyurl.com/oruu25r**

8.6.2 Unstable soil or rock matrix

SuDS for sites where there are soils or rocks prone to instability should not use infiltration as a runoff destination, and it may be necessary to line systems to prevent any water infiltrating the ground. This will depend on the risks associated with any potential instability and the likely volume of water discharging to the infiltration device when compared to natural exposure to rainfall on the same area. A small amount of infiltration to provide Interception may not be a problem.

Using infiltration drainage in chalk can cause settlement due to solution of the chalk or infilled features in the surface of the chalk. Guidance is provided in Lord *et al* (2002).

The use of SuDS in such areas with rock/soil instability risks will require advice from a geotechnical specialist. Areas that need specific care include the areas around old shafts or adits into mine workings, shallow mine workings, limestone and areas with buried, infilled solution features. Shafts and adits and infilled solution features have often been filled with loosely compacted soil that has very marginal stability. The passage of water through it can cause loss of material, as fines are washed out, leading to collapse of the soil mass.

8.6.3 Risks to slopes and/or retaining walls

If water is allowed to infiltrate behind slopes or retaining walls, it can increase pore pressures in the ground. This may increase the pressure on the wall or slope and cause it to fail. Infiltration devices should be located at a sufficient distance from slopes and retaining walls to prevent any adverse effects on stability. The appropriate distance should be based on a slope/wall stability and groundwater flow assessment.

8.7 SITES WITH VERY DEEP BACKFILL

8.7.1 The issues

When designing a surface water management system on a site located above or close to infilled open cast sites or old landfill sites, the following issues should be considered within the design process:

- Infiltrating water can cause compaction of the existing fill material.
- Any settlement of the backfill is likely to cause surface level changes, which can potentially affect gradients along a drainage system or cause damage to liners. Settlement can cause tension cracks that allow more water to infiltrate, which may not be acceptable. This issue may affect the viability of an entire development. So if the site is suitable for development over the backfill then it will most likely be suitable for some form of SuDS.

8.7.2 Fill compaction

The main concern is the potential effect of infiltration on settlement of deeper areas of fill. Infiltration should be avoided unless it can be demonstrated that the fill material is sufficiently well compacted that settlement will not be a problem (as well as being sufficiently permeable).

As shown previously in **Figure 8.4**, a drainage scheme has used permeable paving over a landfill site in Portsmouth. The system is lined to prevent infiltration.

8.7.3 Surface settlement

SuDS such as swales and permeable pavements are likely to be more tolerant of movements due to settlement than piped drainage. Where there are potential risks, however, the effect on gradients should be assessed and any liners should be carefully detailed to prevent tearing. Pipe drainage can only tolerate a small amount of movement at the joints.

8.8 SUDS ON FLOODPLAINS

8.8.1 The issues

On some sites, floodplains might be the only available public open space. The role of a floodplain is primarily to mitigate flood risk from rivers or tides, and during extreme events these areas will naturally flood with river or seawater, making them ineffective for use in storing surface water runoff. It is highly unlikely that any storage volume achieved within a floodplain would be allowed to meet a development's total surface water attenuation requirement. All storage volume should normally be provided within the development footprint, outside of the floodplain.

The presence of a floodplain, however, should not preclude the site from including SuDS, as they could still be effective in managing routine rainfall, and runoff may need to be discharged safely across the floodplain. SuDS in the floodplain may also be acceptable in terms of providing treatment for frequent events. The design of those parts of SuDS in a floodplain should not reduce floodplain storage or conveyance.

8.8.2 Design considerations

Any SuDS within a floodplain should be selected and designed taking account of the likely high groundwater table and vulnerability to erosion during periods of high flows/water levels.

Design of any conveyance routes should limit grading and the creation of surface features (such as berms and unreinforced channels) that could either reduce floodplain capacity or be washed out in a flood. Surface discharge from SuDS should be dispersed (ie allowed to shed off as sheet flow) with point discharges minimised or eliminated.

All SuDS within or crossing a floodplain should take full consideration of the likely influence of river water levels on the design performance (in terms of level, frequency, duration and impact on SuDS conveyance and storage). Combined probability assessments may be required.

Siltation and subsequent clearance after a flood event has subsided should also be taken into account in the design.

The SuDS shown in the development in Stamford in **Figure 8.2** are located in the flood plain.

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Image courtesy Oxfordshire County Council

9 DESIGNING FOR ROADS AND HIGHWAYS

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Designing for roads and highways

This chapter addresses specific design opportunities and constraints when implementing SuDS primarily in or adjacent to roads in new developments. It does not cover retrofitting SuDS into existing roads in any detail, although much of the advice may be relevant in that context. It is not intended to be a complete guide to designing SuDS for roads, as this is provided in other publications.

▶ *This chapter should be read alongside Chapters 3–8 and Chapter 10 in order to understand the many issues that influence the selection of appropriate SuDS for roads.*

9.1 INTRODUCTION

The drainage of roads using SuDS is a design application scenario that has specific challenges owing to the need to protect the road pavement from damage and ensure that extra safety risks are not introduced by the design of the drainage system.

Road/highway design requirements will also be a key influence, and there needs to be co-operation between road/highway and SuDS designers to achieve the most effective schemes.

This chapter is not intended to be a complete guide to designing SuDS for roads. It covers the following specific concerns and issues that are often raised:

1. general road drainage approval issues
2. interface with buried utility services
3. examples of SuDS components used for road drainage
4. use of infiltration systems for road drainage
5. filter drain design issues
6. swale design issues
7. exceedance flow management
8. treatment of road runoff
9. safety issues
10. retrofitting SuDS for road drainage as part of a highways improvement scheme (but not standalone retrofit of SuDS)
11. maintenance issues.

There is other guidance on designing SuDS specifically for roads (including highways), and this is referenced at the end of the chapter (**Section 9.14**).

9.2 APPROVAL AND ADOPTION OF SUDS IN OR ADJACENT TO ROADS

Roads, over which there is a public right of passage, have to be constructed to an agreed standard, with prior technical approval for the design having been secured by the developer from the relevant highways authority. Any road design must also include details of how the road surface is to be drained and what drainage components are to be employed.

Currently, surface water drainage components that drain only an adopted road have to be approved by the local highway authority. Their design may also require approval by the drainage approving body, which could differ from the highway authority. (Although it would normally be in the same local authority, it could be different departments.) If SuDS components drain both the road and adjacent parts of the development, it is more likely that the drainage system will be approved and adopted by the drainage approving body. In the case of pervious surfaces acting as the road surface, this element of the system is likely to be adopted by the highway authority, whether or not they adopt the underlying drainage layer. This is a complex area, and guidance on relevant approval and adoption protocols should be sought from local stakeholders before SuDS design.

Discussions should be held early in the design process to ensure that SuDS for roads are designed to the standards required by the relevant adopting body. It is advisable to consider drainage from roads specifically during the master planning process, taking account of local road (including street) design guidelines and engaging the local highways authority representative, so that a cost-efficient solution can be determined that benefits private property owners, drainage authorities and the highways authority (**Chapter 7**).

9.3 INTERFACE WITH BURIED UTILITY SERVICES

The layout of buried utility services needs to be considered as part of the SuDS design. As far as possible the services should be located in corridors, and the choice of SuDS should recognise their presence. For example, using pervious surfaces over services may not be appropriate in a road where uncontrolled excavation by utility companies could damage the system and lead to flooding. Conversely there are many large commercial sites where concrete block permeable paving has been constructed over buried services without any issues.

Another constraint posed by buried services is where surface features have to be connected below a road. The presence of utilities below the road will lead to the surface water system below the road (usually a pipe) being at least 1 m deep so that they are below the normal services and so the risk of damage by excavation is minimised.

9.4 CONNECTIONS BETWEEN FEATURES BELOW ROADS

Connections between surface features will often have to pass below roads. Normally the most effective way to provide the connection is to use a pipe (or pipes). The pipes are usually required to be placed as shallow as feasible to minimise the depth of the surface features (as this can potentially impact on the design, cost and benefits associated with the drainage system). However, in addition to the constraints imposed by services described above, the cover depth to protect a pipe from traffic loadings is normally 1.2 m, although they can be placed at shallower depth if the strength is increased or they are surrounded in concrete.

If consideration is being given to placing pipes at shallower depth than usual, the risk of damage by utility companies should be assessed.

There are also concerns about shallow concrete surrounds causing hard spots in the pavement construction. If the pavement is not heavily trafficked and has been constructed correctly (especially compaction of materials) this is not likely to damage the pavement surface or affect its performance.

9.5 APPLICATION OF SUDS FOR ROAD DRAINAGE

There are several SuDS components that are particularly suitable for draining roads.

Pervious pavements (**Chapter 20**) are often used for low trafficked roads, particularly in residential areas. These can include permeable paving, porous asphalt, pervious concrete or reinforced grass systems (**Figures 9.1 to 9.3**).

Figure 9.1 Concrete block permeable paving used for a residential road, Cambridge (courtesy Cambridge City Council)

Figure 9.2 Concrete grid grass reinforcement along tramlines, Switzerland (courtesy EPG Limited)

Figure 9.3 Swale and wetland systems with reinforced grass used in less trafficked areas such as laybys and field access points, A16, Lincolnshire (courtesy EPG Limited)

Swales (**Chapter 17**) are an extremely useful method for draining long stretches of road where the road is close to existing ground level and there are few buried services alongside or crossing the road. Swales are usually not suitable where roads are located on embankments unless they are lined (because any infiltrating water could cause stability issues) or where the available space is limited. Other longitudinal drainage components include **filter strips** (**Chapter 15**), which can be used for initial treatment, and **filter drains** (**Chapter 16**), which take less space, but tend to provide less storage capacity than swales and can clog more easily. The provision of an underdrain to the swale can allow for crossing points without disrupting conveyance flows.

Figure 9.4 Swale on a steeply sloping road, Oxfordshire (courtesy EPG Limited)

Figure 9.5 Swale and wetland system, A16, Lincolnshire (courtesy EPG Limited)

The profiled edge paving shown in **Figure 9.4** traps silt and limits vehicle overrun. The check dams reduce conveyance velocities.

Figure 9.5 shows the swale and wetland system used for the A16 in Lincolnshire. In some places surface water runs directly from the road surface into the swale; in others edge channels collect and discharge to the swale (eg from areas of road on low embankments where water flowing down the slopes could cause instability); and in others (where kerbs are required) the kerb drainage collects surface water and discharges to the swale.

Detention basins, ponds and wetlands (**Chapters 22 and 23**) may be suitable for roundabouts or junctions, and are also used extensively on the motorway and trunk road network, where there is space in open countryside.

Figure 9.6 Filter drain, A7, Dumfries and Galloway (courtesy Hydro International)

Figure 9.7 Detention basin draining a rural road, Oxfordshire (courtesy EPG Limited)

The detention basin shown in **Figure 9.7**, draining a rural road in Oxfordshire, has simple dropped kerb inlets into a filter strip zone trap silt. Low mown grass around the edges ensures that site lines are maintained. Other areas drain into the basin via pipes.

Bioretention systems (**Chapter 18**) can be fitted within road build-outs as traffic calming features and within dead space in car parks or turning areas, providing amenity and biodiversity benefits within urban areas.

Proprietary silt traps, proprietary treatment systems, oil interceptors, gully and pipe systems (**Chapter 14**) may form part of a cost-effective road drainage solution where space is particularly limited or other site constraints are present. Early engagement with the adopting body and those that would have responsibility for maintenance is necessary to ensure their acceptability and viability.

For example, hydrodynamic vortex separators have been used to treat pollution from road runoff on a scheme to widen the M25 (**Figure 9.10**). An oil separator is preceded by a large sediment trap and leads to a sedimentation channel and attenuation basin.

Figure 9.8 Wetland draining a complex traffic island, M4 junction 11, Reading (courtesy EPG Limited)

Figure 9.9 Bioretention system, inner ring road around Ashford town centre (courtesy Kent County Council)

Attenuation storage (Chapter 21) may be appropriate in space constrained areas. It may be combined with solutions such as swales or bioretention. There are many examples where road drainage attenuation tanks have been adopted by highways authorities or have been used on motorways, especially as part of widening schemes.

Figure 9.10 Installation of vortex separator, M25 (courtesy Hydro International)

Figure 9.11 Geocellular storage below roundabout, A595 Parton to Lillyhall (courtesy Hydro International)

9.6 ALLOWING WATER TO INFILTRATE IN CLOSE PROXIMITY TO THE ROAD PAVEMENT

Normal road pavement materials are affected by the presence of water, which gradually weakens them and leads to defects such as potholes. SuDS that are adjacent to normal pavement construction should therefore be designed to prevent water infiltration into the pavement or into the soils below it, as they may lose strength if excess water is present. If surface water depths in the adjacent drainage components are kept low, then the infiltrating water will flow downwards and not sideways, and simple details such as that shown in Figure 9.12 can prevent water from flowing into the adjacent pavement structure.

Retrofitting SuDS as part of highway improvement works may well encounter older types of road construction, and the design needs to recognise and be sympathetic to this. The system in Figure 9.12 would be provided with an overflow to the underdrain, and this can allow access for cleaning if necessary.

Swales located next to roads should not, in normal circumstances, be very deep for safety reasons. If there are outstanding concerns regarding risks associated with infiltrating water, swales can be underdrained, which will act as a subsurface drain at the side of the road (Figure 9.13 and HA 33/06 – see Section 9.14). For very shallow swales and low-speed roads a side slope of 33% may be acceptable both from a safety and maintenance perspective (this will depend on the planting design and maintenance regime). For faster roads and deeper swales 25% side slopes may be more appropriate to address safety concerns and make simple grass mowing easier.

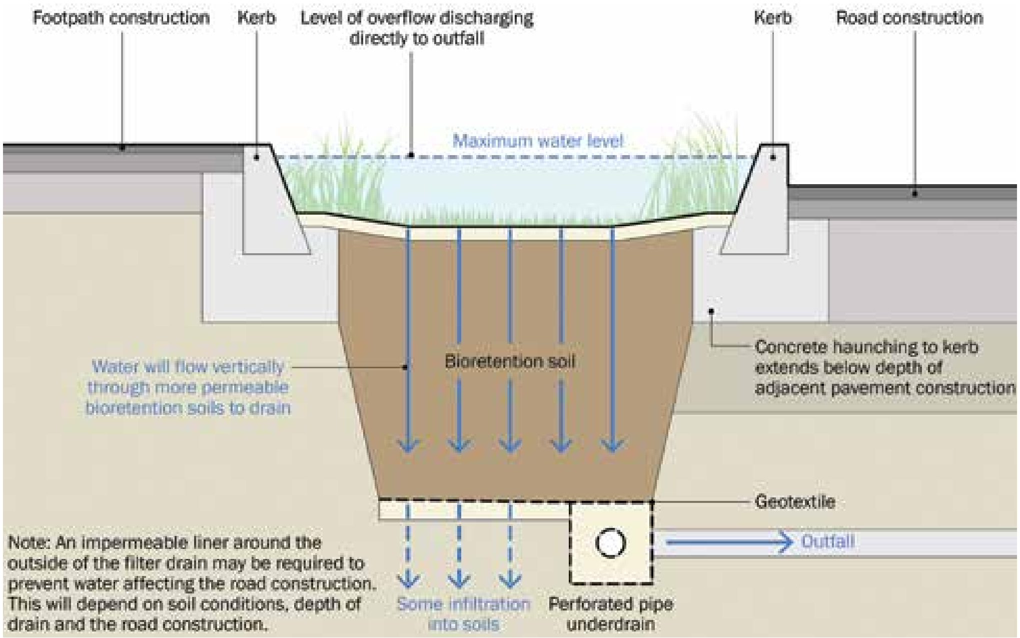

Figure 9.12 Detail of a bioretention system designed to prevent water ingress into adjacent sub-base

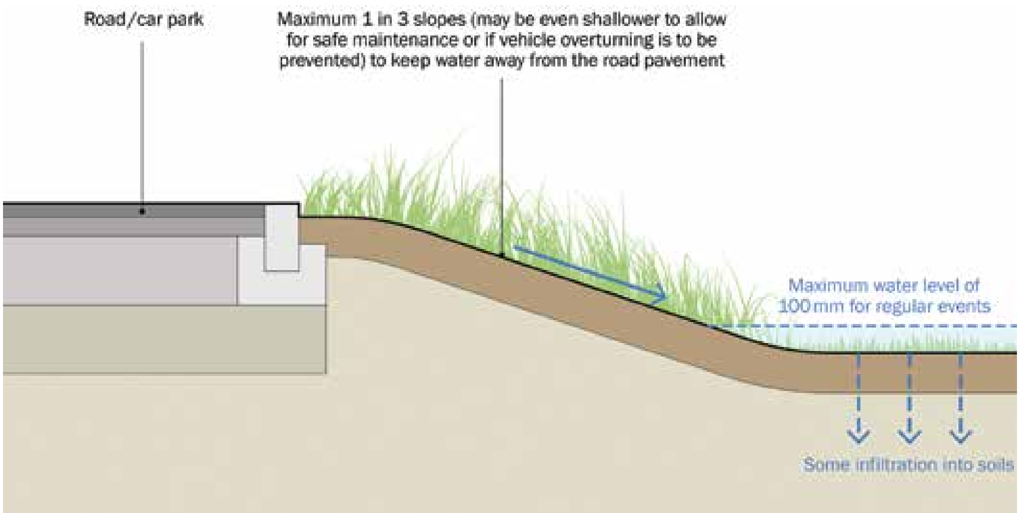

Figure 9.13 Water flows from shallow swales acting as edge drains for the road sub-base

9.7 FILTER DRAINS FOR ROAD DRAINAGE

Highways England (formerly the Highways Agency) has used filter drains as combined surface and subsurface drains for many years (HD 33/06 – see Section 9.14) but there are a few performance issues that need to be considered:

- There is a risk of stone scatter from the surface of filter drains.
- Slopes on the sides of embankments can fail due to water ingress.
- Water can cause pavement failures (filter drains often have larger depths of water than swales and tend to be located closer to the pavement structure, therefore the risk of ingress is greater).
- If not maintained, the risk of clogging and blockage can increase the risk of surface water flooding and also water ingress to the road pavement construction. The risk of clogging can be greatly reduced by allowing water to run over a 1 m width of grass filter strip before the filter drain, if this is possible within the constraints of road/highway design.

The greater the distance from the filter drain to the main carriageway, the less the problem caused by stone scatter and the less the effects of water on the pavement. If necessary, the filter drain could be lined with an impermeable membrane to prevent water ingress to the adjacent road pavement construction.

HD 33/06 (**Section 9.14**) provides information of relevance to the design of filter drains for roads/highways. A general filter drain detail for roads is shown in **Figure 9.14**. The boundary between the impervious area and the vegetation is key to ensure success with this design. This can be an area of significant erosion, compaction, sediment build-up and contamination that has to be considered in the design and maintenance requirements. The significance of these issues increase as the traffic frequency and area drained to the edge increases. On heavily trafficked roads this edge may need frequent maintenance to remove silt.

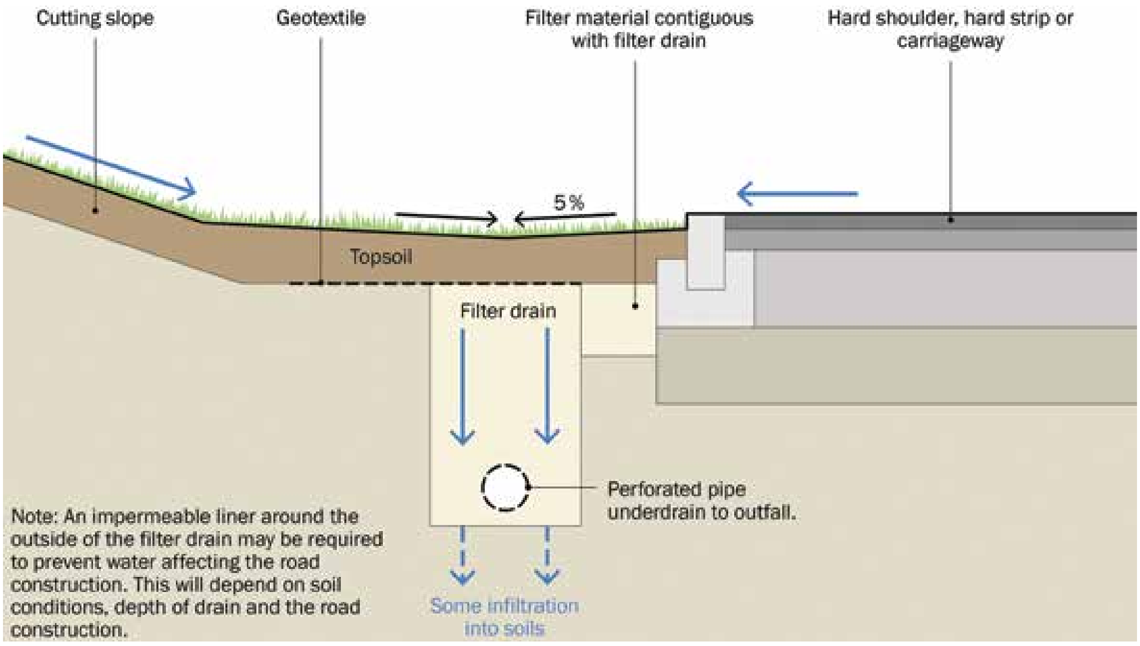

Figure 9.14 Filter drain details for cuttings – combined surface water and groundwater drainage

9.8 SWALES FOR ROAD DRAINAGE

Highways England has used grassed channels as surface drains for highways for many years (HD 33/06 – see **Section 9.14**) but the following needs to be considered:

- The profile and location of the channel should not pose a hazard to traffic.
- The swale should be designed to allow easy access for maintenance.
- The swale should be designed so that water ingress into the ground will not affect the adjacent pavement construction. If necessary the swale can be lined with an impermeable geomembrane.

HD 33/06 (**Section 9.14**) provides information of relevance to the design of swales for strategic trunk roads/highways and motorways. Although not completely applicable to other roads, it does contain useful information that can be used and adapted by designers of swales alongside other roads. A general swale detail for roads is shown in **Figure 9.15**.

Kerb drains can be an effective way of collecting water from road surfaces and discharging it at shallow depths into swales. (The rear outlets from the kerb drain to the swale should be at very regular spacing to keep flow rates low and minimise the risk of erosion.) In **Figure 9.16** the roof water from the houses discharges into the kerb drains that are draining the road. The kerb drain discharges to the channel drain across the road which in turn discharges to the swale at the right of the picture. This keeps the swale very shallow. The system has been adopted by the local highways authority (Oxfordshire County Council).

Another kerb drain outlet directly into a swale is shown in **Figure 9.17**.

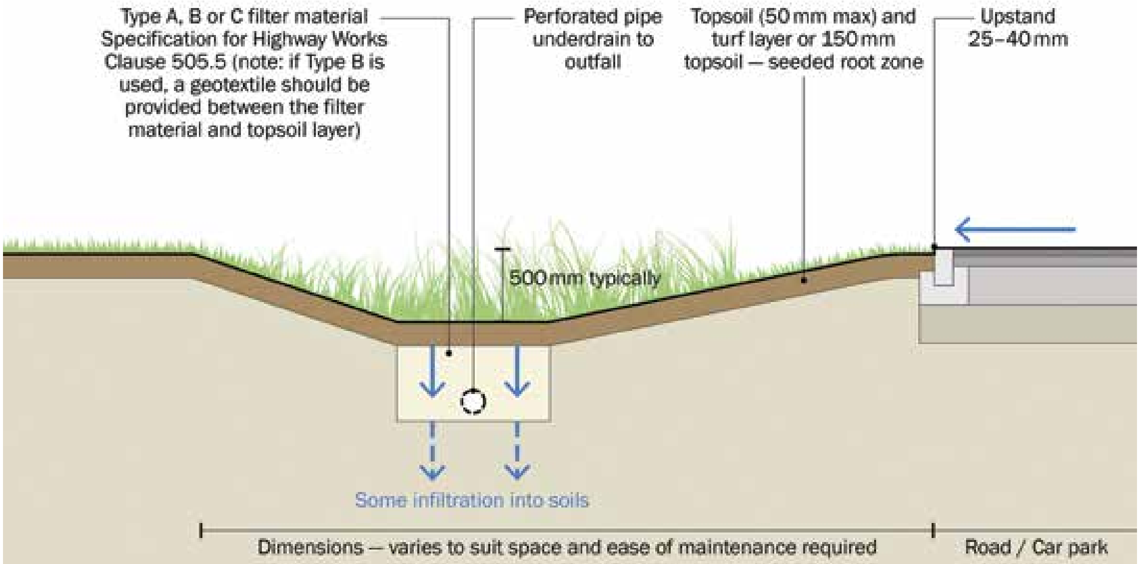

Figure 9.15 Swale detail

Figure 9.16 Kerb drains and channel connected to swale (courtesy EPG Limited)

Figure 9.17 Outlet from kerb drain into swale (courtesy ACO Limited)

Figure 9.18 Swale set back from road, Elvetham Heath (courtesy Hydro International)

Figure 9.19 Highway acting as a flood pathway in an exceedance event (courtesy Simon Jeffrey)

9.9 ROADS FOR EXCEEDANCE FLOW MANAGEMENT

Roads can provide routes for flows that exceed the capacity of the drainage system (**Figure 9.19**). Further guidance is provided in Balmforth *et al* (2006) and Digman *et al* (2014).

Roads can be designed or modified to maximise their exceedance flow conveyance or storage capacity, but great care is needed to ensure that the flows do not cause problems further downstream and do not represent a hazard to vehicles and pedestrians.

Road designs can be modified to act as efficient exceedance routes by various methods including:

- raising kerb heights (within acceptable limits of road design)
- removing drop kerbs (if practical)
- reprofiling ground levels behind drop kerbs
- introducing dropped kerbs or reprofiling to allow water to run from the road carriageway into suitable open areas of land adjacent to the road
- raising sections of carriageway to provide a dam that allows further storage and attenuation of exceedance flows. This can often be integrated with, or be part of, traffic management schemes (eg speed humps).

Where the road is drained using conventional pipework, the number and capacity of road gullies will determine the division of flows between the subsurface system and the road. These should be optimised so that flood risks are managed most effectively.

9.10 TREATING ROAD RUNOFF

For the design of roads in development sites the general guidance on water quality principles and criteria provided in **Chapter 4** should be followed. For trunk roads and motorways that are the responsibility of

Highways England, there are specific guidance documents and risk assessment approaches provided in HD 45/09 (**Section 9.14**). HD 33/06 (**Section 9.14**) also includes indicative treatment efficiencies for drainage systems and guidance on appropriate combinations of vegetative and proprietary systems.

Gully emptying, road sweeping and other road maintenance tasks are important pollution prevention strategies for road runoff, and the treatment of the runoff at or close to its source should be a priority (**Chapter 27**).

Winter maintenance activities and particularly the gritting of roads can have adverse impacts on the health of vegetation next to roads. Planting should be specified that is as tolerant as possible of potential higher chloride levels in winter runoff. The winter performance of pervious surfaces is discussed in **Chapter 20**.

In order to maintain the filtration capacity of vegetation systems at the edge of roads it is necessary to protect them from rutting caused by vehicle overrun.

9.11 DESIGNING SAFE SUDS ADJACENT TO ROADS

Any drainage system needs to be safe and there are specific safety considerations for components that lie adjacent to roads. The risk of a vehicle overturning and the ease of maintenance are the main issues to consider when decided on an appropriate slope to the side of the swale. For swales next to high-speed roads, Highways England specifies a maximum slope to the swale of 1 in 5 and a maximum water depth of 200 mm (HA 119/06 – see **Section 9.14**). For slow-speed access roads in residential areas a side slope of 1 in 3 is more appropriate if the swale is very shallow. Discouraging vehicle overrun with profiled paving (as shown in **Figure 9.4**) is also useful in this respect.

Vegetation in SuDS should not interfere with sight lines. In **Figure 9.7** the grass around the edge of the detention basin is cut regularly to maintain site lines. The vegetation in the centre of the detention basin can be left to grow higher.

9.12 RETROFITTING SUDS FOR ROADS

The most likely occasions where retrofitting into an existing road drainage system could be considered to be practical and cost effective are:

- during road reconstruction/resurfacing schemes
- during large-scale drainage improvement schemes
- increased residential expansion in urban and rural schemes.

Further information on retrofitting SuDS is provided in Digman *et al* (2012). The overriding factor in choosing suitable locations for retrofitting SuDS will be the existing falls on the carriageway and the location and depth of buried services. Before any design work on a retrofit SuDS is undertaken, a comprehensive utilities and topographical survey should be completed so that the SuDS can be designed around the buried services and existing levels.

In dense urban environments, roads constructed before the 1950s could include crushed rock or hoggin sub-base (hoggin is an as-dug mixture of clayey sand and gravel common in the south-east of England), clinker construction, granite sett construction or wooden tar block construction. Designing around these types of construction is site-specific. Care needs to be taken that the SuDS will not adversely affect the construction by allowing water into it and the impact of breaking into the construction does not compromise the long-term stability of the pavement. Breaking into concrete pavements to construct SuDS also needs to be done with care to ensure that the stability of the pavement is not adversely affected.

When retrofitting SuDS to existing roads, the gradients and kerb levels will be an important influence on drainage paths. Designers should always check existing gradients and finished kerb height levels and assess any likely future changes that may occur as a result of maintenance works to ensure that the SuDS will drain the road effectively in the long term.

When retrofitting SuDS in rural roads, how the road is constructed, drained and maintained will influence the design. A large proportion of rural roads have been maintained by having had many applications of surface dressing (chip and tar), so levels and falls will simply follow the original profile (which will have been a cart track). If the road is reconstructed to modern standards the cross falls and longitudinal gradients may change and water may not flow to the SuDS.

It is impossible to provide a completely water-tight road construction, and there is always a level of moisture within any road construction, especially in the sub-base. It is important that, in addition to not increasing the moisture levels, the retrofit SuDS does not cut off existing drainage paths within the sub-base.

Further advice including potential retrofit opportunities for SuDS adjacent to roads is provided by Pittner and Allerton (2009).

9.13 THE MAINTENANCE OF SUDS ADJACENT TO ROADS

The maintenance requirements for SuDS alongside roads are no different from those in other situations, and reference should be made to **Chapter 32**, and also to the individual technical component sections of this manual.

SuDS draining roads should be reinstated and established correctly, if service companies dig trenches through them. The profile of a swale should be reinstated to the correct levels and use appropriate topsoil and seeding. The repair will need to be protected from erosion until the vegetation is fully established. Pervious surfaces and bioretention systems will require the correct permeable materials to be used in reinstatement.

Wherever SuDS are present over buried services they are an engineering problem in the event of excavation, and the road should be classified as a street with special engineering difficulties (SED) under the New Roads and Street Works Act (NRSWA) 1991. Further information on SEDs and the NRSWA is provided by the Department for Transport (2012).

9.14 ADDITIONAL GUIDANCE RELEVANT FOR SUDS DRAINING ROADS

Pittner and Allerton (2009) provides guidance on SuDS design and implementation for road surfaces.

The Design Manual for Roads and Bridges (DMRB) (HA, 2014) includes the following guidance relevant to SuDS:

- HD 33/06 *Surface and subsurface drainage systems for highways*
- HA 37/97 *Hydraulic design of road edge surface water channels*
- HD 45/09 *Road drainage and the water environment*
- HA 78/96 *Design of outfalls for surface water channels*
- HA 83/99 *Safety aspects of road edge drainage features*
- HA 80/99 *Surface drainage of wide carriageways*
- HA 102/00 *Spacing of road gullies*
- HA 103/06 *Vegetated drainage systems for highway runoff*
- HA 105/04 *Sumpless gullies*
- HA 118/06 *Design of soakaways*

- HA 119/06 *Grassed surface water channels for highway runoff*
- HA 217/08 *Alternative filter media and surface stabilisation techniques for combined surface and sub-surface drains*

These documents refer to design for the strategic road network (SRN) and local highway authorities (LHAs) should refer to published guidance if they wish to adapt this guidance for use on their networks (UK Roads Liaison Group, 2011). The use of standard designs and specification is useful and can avoid many pitfalls. However, it should be recognised that effective design often requires standard requirements and specifications to be adapted to particular circumstances that apply to a site.

It is only trunk roads that are required to be designed according to the DMRB and in the Manual of Contract Documents for Highway Works (MCHW) Specification for highway works (HA, 2005). For all other roads, the decisions on the choice of standards and their incorporation into designs remain in the hands of local highway authorities.

The UK Roads Liaison Group's document has been written to assist highway authorities assessing *"departures from Highways Agency's Standards"* and designers preparing submissions. The stated aim is that the departures process should be viewed as an opportunity to simply and effectively record the best judgements of the professionals involved in the delivery of a road/highway scheme, rather being overly bureaucratic.

The DMRB is frequently amended to reflect advances in design and construction practice, and therefore the list above should not be considered exhaustive and designers should check whether updated version have been published.

Designing streets (The Scottish Government, 2010) provides a policy statement in Scotland for street design with an emphasis on place-making, including the use of SuDS.

Manual for streets (DfT and DCLG, 2007) provides guidance on design, planning and approval of new residential streets and modifications to existing ones.

Manual for streets 2 (CIHT, 2010) is a companion guide to the *Manual for streets* and demonstrates through guidance and case studies how the philosophies set out in *Manual for streets* can be extended beyond residential streets to encompass both urban and rural situations. It is intended to fill the perceived gap in design advice between the *Manual for streets* and the DMRB.

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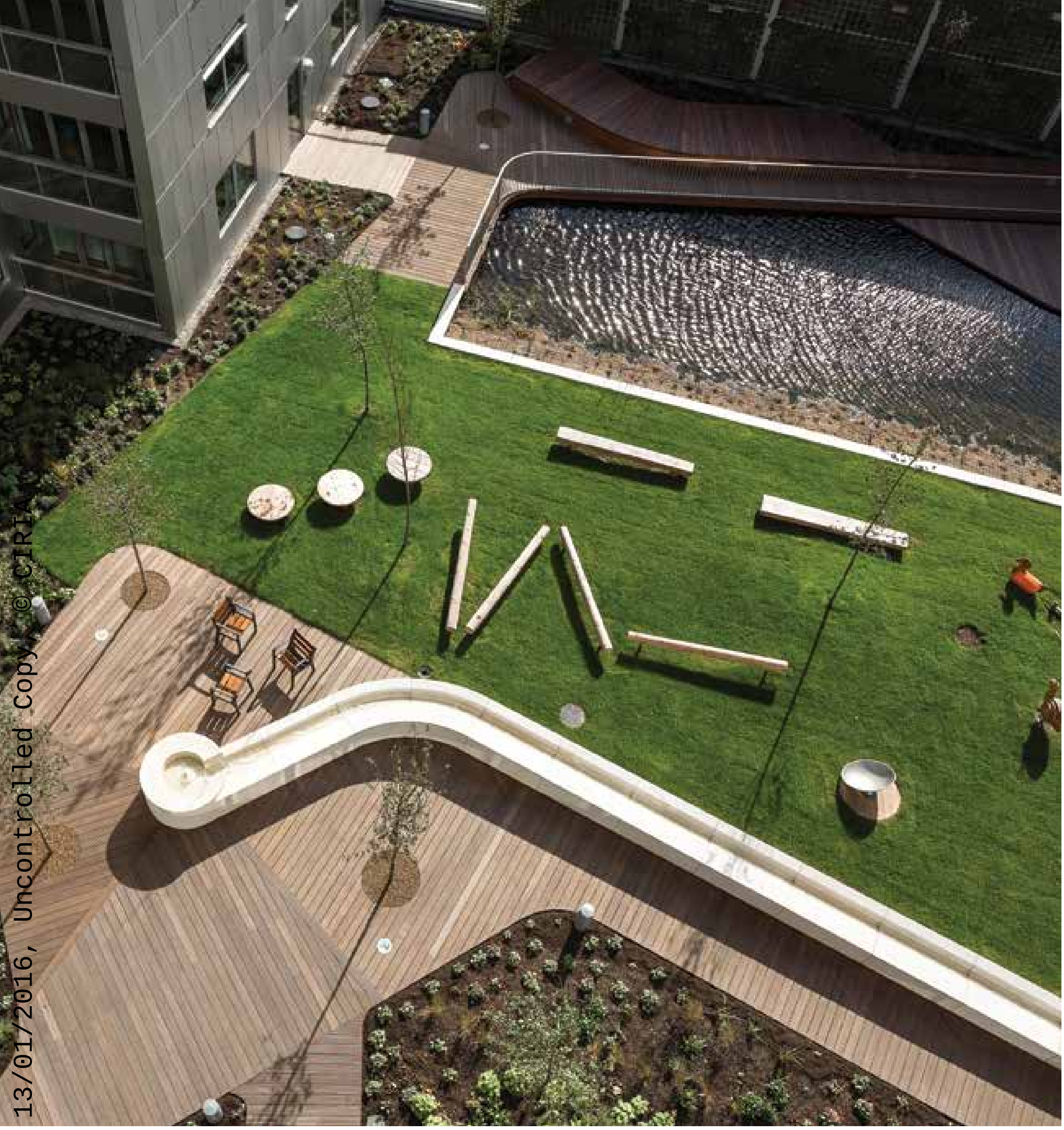


Image courtesy Tim Crocker

10 DESIGNING FOR THE URBAN ENVIRONMENT

Contents

Chapter 10 Designing for the urban environment

This chapter sets out how to evaluate the opportunities and challenges associated with implementing SuDS for high density new development and sites within existing urban areas (redevelopment sites, infill sites and retrofit sites). Much of the guidance is also relevant for suburban sites.

It discusses how to design schemes that deliver effective surface water management, while maximising amenity and biodiversity benefits for urban communities, by following the SuDS design criteria set out in Chapters 3–6.

The images and illustrations provide urban planners, architects, landscape architects and drainage designers with examples of the different options and opportunities available. Example SuDS solutions for different types of urban development are presented as a set of nine 'typologies'.

▸ *This chapter should be read alongside Chapters 3–9 in order to understand the many issues that influence the selection of appropriate SuDS for the urban environment.*

10.1 OBJECTIVES FOR SURFACE WATER MANAGEMENT IN THE URBAN ENVIRONMENT

10.1.1 Surface water management and urban design

Surface water management should be an integral part of urban design

Successful integration of SuDS into urban design requires:

1. early consideration of surface water as part of an integrated design process
2. a collaborative, interdisciplinary design team that brings together developers, engineers, planners, landscape architects, architects, ecologists and the local community.

Surface water management should be considered at the very early stages of urban planning (Chapter 7), to help shape and enhance the overall vision for the area, whether this is part of, for example, the redevelopment or regeneration of an existing urban area, infill development, a new large high-density development or part of a green infrastructure strategy. By adopting this approach, designers can make best use of the space available, delivering cost-effective multi-functional developments.

▶ See the Rathbone Market case study in Section 10.4.

Flooding and poor water quality are the main drivers for surface water management. The high proportion of impermeable surfaces, high pollution loads in surface water runoff and limited sewer capacity have left a legacy of problems for our urban areas. However, there are other issues facing our urban areas that can be addressed by improving the way that surface water is managed. For example, natural drainage systems and green space have often been lost or severely fragmented, leaving a degraded ecological landscape. The combined effect of large expanses of hard surfacing and less green space means that cities are warmer than the surrounding areas (the urban heat island effect), which can result in uncomfortable living conditions and health problems during periods of hot weather. Areas of planting or open water, and features that retain water can help reduce the temperature of urban surfaces during hot summer periods. Trees can help shade buildings, reducing internal air temperatures, and green roofs can improve a building's thermal insulation properties.

The challenge of managing surface water effectively within the urban environment is intensifying with climate change, continued urbanisation and urban creep. Climate change projections indicate that more intense rainfall and higher temperatures will become more frequent in the UK. The density of development is also increasing and, with this, competition for the use of space is exacerbated. This means that reversing urban creep and maximising the multi-functionality of urban space is essential (**Section 10.2.6**).

The challenge for designers and planners is to create integrated urban spaces that include SuDS in creative and innovative ways, taking into consideration their potential contribution to a range of functions, such as flood risk management, water supply, green infrastructure, habitat provision, transport corridors, climate proofing, community identity, recreation and tourism. In this way, SuDS can make a significant contribution to the delivery of a wide range of local planning policies and objectives.

10.1.2 SuDS and urban place-making

SuDS can make a significant contribution to improving where we live and work

Good urban design should be about 'place-making' – all urban design projects should have a strong focus on the people and community that will inhabit and use the space, providing opportunities for people to interact with each other and their environment.

People have always been drawn to water in the urban environment, due to the beauty it can create in the landscape, its calming and cooling effects and its use for recreation. The positive presence of water within the urban environment can promote a strong sense of place, creating unique spaces that can be enjoyed by all. Features such as reflective pools, ponds, fountains, water playscapes, planted rills etc, if designed creatively, can help to bring an urban space to life and connect people, nature and water.

SuDS can make a significant contribution to supporting urban communities. People are more likely to feel that they belong to the local community and take a greater pride in their neighbourhood where they have opportunities for human interaction, such as recreational facilities and places to congregate. This in turn can have a wide range of secondary benefits, such as encouraging businesses to move into the neighbourhood, investment in amenity facilities and events and visitors to come and spend money. It can even lead to crime reduction. These benefits are discussed in more detail in **Chapter 5**.

Effective consideration of urban community needs and opportunities during the design stage can help maximise benefits (**Chapter 34**). For example, green spaces have an important role to play in improving the health and well-being of the urban population, as they can contribute towards the improvement of air quality, provide shade and urban cooling, as well as help play a part in surface water and wider flood risk management strategies for the area.

▶ See the Bristol Harbourside case study in **Section 10.4**.

Connected green infrastructure can facilitate walking and cycling routes within tranquil settings and recreational green space. These benefits in turn provide opportunities for people to come into contact with nature, to experience the seasons, to become more active and to live and work in a more attractive and stimulating environment, all of which are proven to have positive effects on health and well-being.

10.1.3 Finding space for SuDS

Good SuDS design maximises the use of the available space

Sites within urban areas are often confined and restricted. Planning and design constraints are often tighter than at other sites, and land is often more valuable. Introducing SuDS can appear challenging when faced with competing development objectives, but SuDS can be integrated into a development without negatively impacting upon the primary function of the urban space (**Case study 10.1**).

CASE STUDY 10.1 **Hunter Avenue, Kent**

Figure 10.1 Hunter Avenue (courtesy Kent County Council)

Working within the constraints of 50 dwellings per hectare, the development at Hunter Avenue incorporates green space effectively, improving the aesthetics and providing opportunities for recreation, while increasing the number of street trees on the site.

Permeable paving with below-ground attenuation is used to manage surface water runoff. Exceedance flows are contained within the road curtilage and parking areas along the southern boundary of the site.

Opportunities for the creation of SuDS can be found in even the smallest spaces, and a perceived lack of space is not a justifiable reason for not using SuDS.

For example, as part of the conceptual design stage (**Chapter 7**) the following potential uses of the site should be considered:

- Can green roofs be used as an alternative to standard roof construction?
- Can roof runoff be harvested in tanks for non-potable use within buildings, such as toilet flushing?
- Are there other potential non-potable uses for surface water runoff (eg landscape irrigation, urban horticulture)?
- Can harvested rainwater be used as a resource for water features and recreational play areas?
- Can impermeable surfaces (roofs, parking, pavements etc) be replaced by pervious surfaces and/or include permeable sub-base in which water can be stored?
- Where impermeable surfaces are necessary, can these be drained to small bioretention systems, open water amenity features and/or tree pits?

- Can private or public landscaped areas use or be redesigned to include tree pits, landscaping planters, rain gardens, bioretention systems or swales to provide storage and treatment of runoff?
- Can small areas in front or back gardens or yards be designed as bioretention planters to capture roof runoff or configured to include rainwater harvesting systems?
- Can proprietary products be used to help control flows, store water and/or provide treatment in confined spaces?

Traditionally, the perceived usable space for SuDS has been confined to what is deemed to be public space – from 'fence to fence' – which can limit the potential for SuDS implementation and a fully integrated approach. Looking at the urban space as being from 'door to door' (blurring the boundaries between public and private land) provides many more opportunities for using space efficiently. Underutilised land often falls along the interfaces between public and private land, such as grass verges and other small pockets of vegetation or paving. Reviewing this land and discussing potential opportunities with landowners and the community can unlock large areas that can be used to enhance the streetscape as a whole as well as supporting SuDS strategies. Facilitating this approach will require effective community engagement, but there is an increasing number of cases where this has been successfully achieved, as discussed in **Chapter 34**.

Integrating SuDS within urban space can also deliver biodiversity benefits. This may be through introducing or enhancing the green and blue space for the site, reconnecting fragmented green space in the surrounding area and/or linking with local green infrastructure.

Examples of where SuDS can enhance green infrastructure include:

- street trees as individual specimens, lines of trees that can connect green spaces together and groves of trees that can form habitat islands (**Chapter 19**)
- management of existing street trees and enhancement by using SuDS to increase air and water availability for tree roots
- maximising the plant coverage by replacing hard barriers with hedges etc
- extensive and intensive green roofs
- green walls and vertical gardens
- using SuDS components such as swales and detention basins within multi-functional landscape features
- using reinforced grass surfaces in place of hard surfaces where appropriate
- raised planters, which can provide temporary storage measures
- diversity of planting and habitat provision.

Urban SuDS should always take a form that responds to the location, character, drivers and opportunities associated with the site. There are a number of components or component derivations likely to be more relevant for dense urban areas. The examples given below are not exhaustive, and different components will develop as SuDS design progresses in the future. All of these types of components are used within the typologies presented and illustrated in **Section 10.3**. Guidance on how to design and implement the SuDS components is provided in **Chapters 11–23**.

PERVIOUS SURFACES

Figure 10.2 Pervious surfaces (courtesy Interpave)

Pervious surfaces can be used in combination with aggregate sub-base and/or geocellular/modular storage to attenuate and/or infiltrate runoff from surrounding surfaces and roofscapes. Liners can be used where ground conditions are not suitable for infiltration. A variety of different surfacing materials are available (**Chapter 20**).

KERB DRAINAGE, RILLS AND CHANNELS

Figure 10.3 Kerb drainage, rills and channels (courtesy ACO, Illman Young)

Kerb drainage, rills and channels can keep runoff on the surface and convey runoff along the surface to downstream SuDS components. They can include inverted road profiles with central surface conveyance in low traffic areas. Some proprietary kerb and channel drainage systems can trap silt and oil from runoff and provide treatment (**Chapter 14**).

PLANTED CHANNELS

Figure 10.4 Planted channels (courtesy Robert Bray Associates, Graham Fairhurst)

Planted channels can provide conveyance routes that treat runoff and attenuate flows. They can be in the form of ground-level planted channels and raised planters. These can form privacy strips along interfaces to reaffirm public/private boundaries and support urban greening.

BIORETENTION SYSTEMS AND RAIN GARDENS

Figure 10.5 Bioretention systems and rain gardens (courtesy Illman Young)

Planted areas and raised planters can be used as rain gardens and other types of bioretention systems, including areas between the road and building elevations, at street intersections or traffic islands, as kerb extensions to create parking bays or traffic calming measures (**Chapter 18**).

SWALES AND LINEAR WETLANDS

Figure 10.6 Swales and linear wetlands (courtesy Essex County Council, Leicester City Council)

Swales and linear wetlands can be used alongside roads and car parks (**Chapter 17**).

ON-PLOT SUDS

Figure 10.7 On-plot SuDS (courtesy Illman Young, Robert Bray Associates)

There are many opportunities for small on-plot SuDS, such as downpipe reconnections to rain gardens, planted rills and water butts.

GREEN ROOFS, GREEN WALLS AND PODIUM DECKING

Figure 10.8 Green roofs (courtesy Sky Garden, Arup)

Green roofs can be used to treat and attenuate runoff in their substrate and support root uptake of water with appropriate planting, while also insulating buildings and reducing the urban heat island effect (**Chapter 12**). Green walls can be used to attenuate roof runoff within their substrate and extensive planting, receiving natural irrigation and supporting natural ventilation and building temperature regulation. Podium landscapes can include geocellular storage and attenuation within pavement build-up on roof terraces and decks.

PUBLIC SPACES

Figure 10.9 Public spaces (courtesy Illman Young, Studio Engleback, Jeroen Musch)

Public spaces can double as shallow detention basins and flood channels, and can also provide opportunities for ponds and wetlands (**Chapters 22 and 23**).

▶ See the Tanner Springs Park case study in **Section 10.4**.

PLAY AND EDUCATION

Figure 10.10 Playful and informative elements (courtesy Planet Earth, Robert Bray Associates, Drain Markers)

SuDS can also be designed to provide opportunities for play and education, as well as communicating their purpose and how they work.

▶ See the Benthemplein Water Square case study in **Section 10.4**.

10.1.4 Retrofitting SuDS

Retrofitting SuDS makes our urban areas more resilient

Retrofitting SuDS is a vital part of the overall strategy for making towns and cities more resilient to future climate change and urbanisation, considering new development only comprises around 1% of land use change within urban areas each year (Adaptation Sub-Committee, 2012). While SuDS for new developments (and redevelopments) can prevent any increase in flood risk from surface water caused by the development, retrofit SuDS can reduce the existing risk.

Retrofitting SuDS into urban spaces is possible in many places. Detailed guidance on the opportunities for SuDS retrofit and the implementation mechanisms are set out in detail in Digman *et al* (2012).

The extent and type of SuDS components that can be used for a retrofit site will be influenced by the specific characteristics of the site. The extent to which a retrofit SuDS scheme can deliver the SuDS design criteria (**Section 10.2**) will depend on the context of the development, land use and the specific retrofit drivers, which will be set by the stakeholders involved in funding and planning the retrofit scheme.

Retrofitting SuDS into urban streets as a standalone project may not always appear to be cost-beneficial. It is often easier and more cost-effective if it is done as part of other works to improve an area, such as constructing traffic calming measures or highway maintenance improvements. Courtyards or other green spaces are ideal for retrofitting SuDS as part of general improvement works. The same is also true for retrofitting to buildings; it is likely to be most cost-efficient to retrofit SuDS to buildings as part of a wider programme of repairs, renovation, upgrading or extension.

▶ See the Derbyshire Street case study in **Section 10.4**.

Increasing economic and development pressures means that land in towns and cities is enormously valuable. In some scenarios (particularly where retrofitting SuDS is being considered) the land required for SuDS should be evaluated strategically through collaboration and partnership working with stakeholders, so that potential benefits beyond site drainage and opportunities associated with joint funding initiatives are identified.

Where retrofitting SuDS, there is also the need to optimise the multi-functionality of existing infrastructure. For example:

- Can existing gullies be used as exceedance/overflow routes for SuDS by adjusting levels of the gulley grating?
- Can bioretention systems or rain gardens be located upstream of existing gullies (**Figure 10.11**)?
- Can existing kerbs/edges be removed or altered?
- Can surface rills and channels be incorporated to replace below-ground drainage?
- Can green roofs be fitted to existing roof structures?
- Can downpipes be disconnected and redirected into plot level rain gardens?

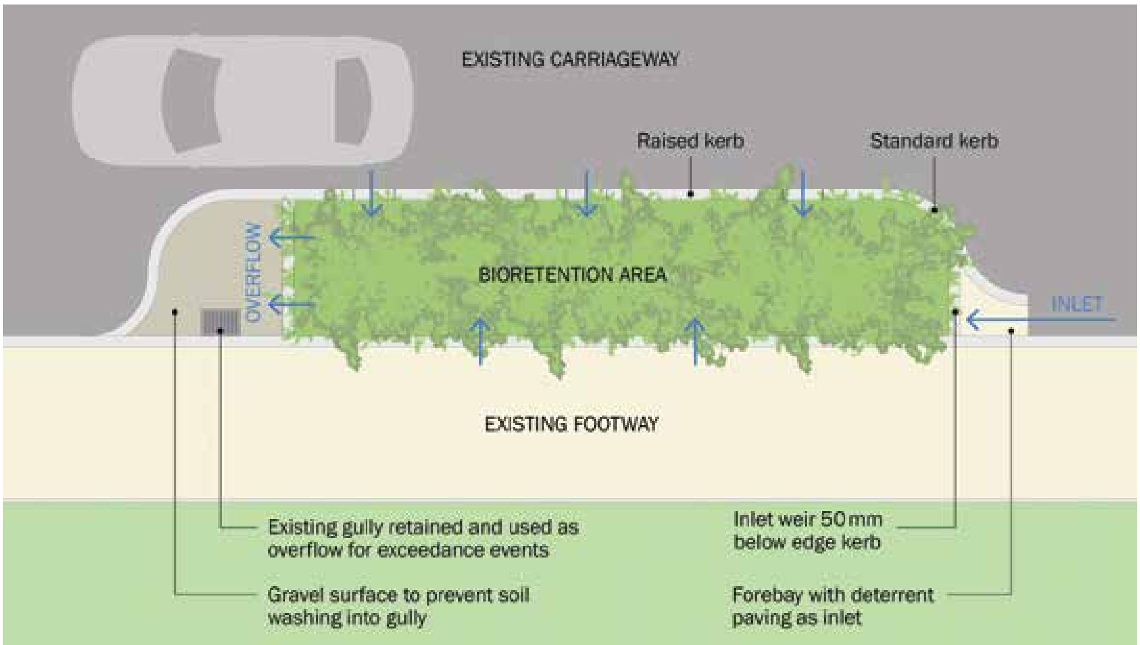


Figure 10.11 Example of a bioretention system upstream of an existing gully (after Illman Young/EPG Limited)

10.1.5 Community engagement

Community engagement plays an important role in successful urban design

Community engagement can be critically important in the design of SuDS in urban areas, as neighbours or existing residents often have a major say in development planning.

Community engagement is essential for the success of any proposed SuDS retrofit scheme, not only to obtain acceptance, but also to identify opportunities for maximising benefits and in the long-term to promote community ownership of the SuDS. SuDS schemes that have tangible benefits for the community may be actively encouraged by residents, if they are well-informed. Working with local environmental and other community groups can help to support, maintain and develop the SuDS and surrounding area.

▶ See the Augustenborg case study in Section 10.4.

Methods for increasing public awareness and encouraging engagement are discussed further in Chapter 34.

10.2 DELIVERING THE SUDS DESIGN CRITERIA WITHIN URBAN AREAS

SuDS can be used successfully in urban areas by following the design criteria described in Chapters 3–6 and summarised in Table 10.1. Supplementary guidance on the specific opportunities and challenges associated with designing and implementing SuDS in urban areas is presented in the Sections 10.2.1–10.2.10. Reference should be made to Chapters 3–6 for further information, and where guidance is sufficient in those chapters for individual design criteria, this is not repeated here.

Many of the design criteria are interrelated, and the total value that can be achieved for a development will be greatest when they are considered collectively as part of an integrated urban design solution. Integrated urban design requires the use of different SuDS components for different land uses and for different development scenarios. It requires a collaborative or multi-disciplinary design process that brings together engineers, planners, architects, landscape architects, developers and the local community.

TABLE 10.1 Summary of SuDS design criteria

	Design criteria	See Section
Water quantity	1 Use surface water runoff as a resource	10.2.1
	2 Support the management of flood risk in the receiving catchment	10.2.2
	3 Protect morphology and ecology in receiving surface waters	
	4 Preserve and protect natural hydrological systems on the site	10.2.3
	5 Drain the site effectively	10.2.4
	6 Manage on-site flood risk	
	7 Design system flexibility/adaptability to cope with future change	Chapter 3
Water quality	1 Support the management of water quality in the receiving surface waters and groundwaters	10.2.5
	2 Design system resilience to cope with future change	Chapter 4
Amenity	1 Maximise multi-functionality	10.2.6
	2 Enhance visual character	10.2.7
	3 Deliver safe surface water management systems	10.2.8
	4 Support development resilience/adaptability to future change	10.2.9
	5 Maximise legibility	Chapter 5
	6 Support community environmental learning	10.2.10
Biodiversity	1 Support and protect natural local habitats and species	Chapter 6
	2 Contribute to the delivery of local biodiversity objectives	
	3 Contribute to habitat connectivity	
	4 Create diverse, self-sustaining and resilient ecosystems	

10.2.1 Water quantity criterion 1: Use surface water runoff as a resource

SuDS provide a unique opportunity to exploit surface water runoff as a resource in urban areas, rather than regarding it as a nuisance and a waste product that should be removed as quickly as possible.

In a dense urban environment, climate change scenarios may mean that periods of water scarcity and associated controls on its use become more common, and the cost of water may rise. By taking opportunities to capture and store runoff (particularly from roofs), a supply of non-potable water can be secured and used either internally for the property (eg toilet flushing) or externally, such as landscape irrigation, urban food growing or as an educational resource for children's play areas (**Figure 10.12**). Guidance on the design of rainwater harvesting systems for surface water management is provided in **Chapter 11**. Rainwater storage tanks can be included on roof space (blue roofs), within roof space, above ground within property curtilage, or below car parking areas.

Surface water runoff is also a valuable resource for the environment: a regular flow of water (if suitably treated) can help to sustain habitats that may otherwise be lost within the urban environment and can provide crucial ecological connectivity between other water bodies nearby (**Section 10.2.3**).

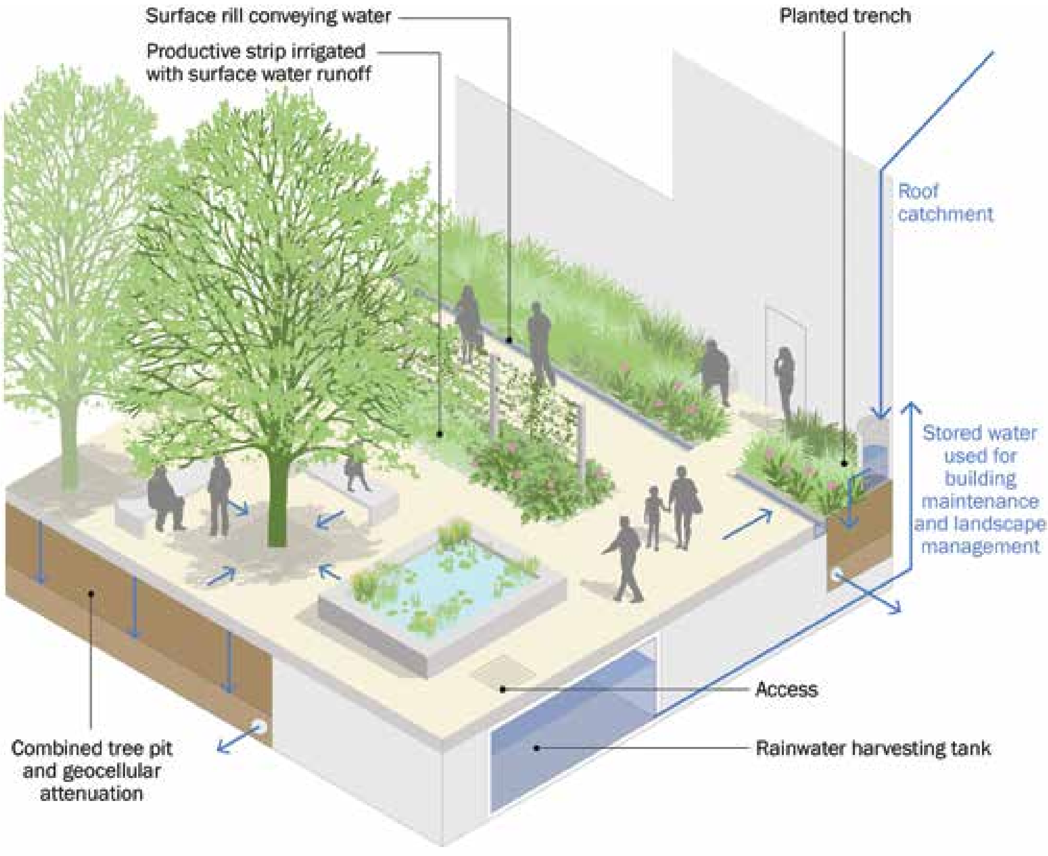


Figure 10.12 Communal space using runoff as a resource

10.2.2 Water quantity criteria 2 and 3: Support the management of flood risk in the receiving catchment and protect morphology and ecology in receiving water bodies

a) Prioritise where surface water runoff is discharged

The destination for surface water runoff that is not collected for use should be prioritised as described in **Section 3.2.3 (part 1)**.

Discharge to existing surface water and combined sewers will sometimes be the only feasible options in existing urban areas. Locating and characterising existing sewerage systems is an important task to undertake early during the feasibility stages, together with consultation with the relevant sewerage undertaker to scope potential opportunities and constraints.

b) Control the volume of runoff discharged from the site

Opportunities for infiltration within existing urban areas are often limited. This means that rainwater harvesting and the use of evapotranspiration from temporary soil moisture (eg green roofs, tree pits, bioretention and other vegetated systems) and gravel media storage zones (eg pervious pavements) are important design tools for delivering Interception (ie volume control for frequent events). Where opportunities for infiltration and rainwater harvesting are limited and cannot reduce runoff volumes sufficiently for extreme events, then storage should be provided so that discharge rates can be controlled to a level that will not adversely affect flood risk (**Section 3.3.1**).

c) Control peak runoff rates from the site

Usually, the most efficient way of designing storage and flow control systems in urban environments is to store and control runoff in small distributed sub-catchments. All available opportunities to provide small-scale surface water storage features should be considered, and the system can then be designed to

Figure 10.13 Rain garden with weirs to control flows on sloping site in Ashford, Kent (courtesy EPG Limited)

provide the rest of the storage below ground. Combinations of rainwater harvesting systems, bioretention/rain gardens, pervious surfaces, green/blue roofs, hardscape storage, microwetlands and trees can usually provide more than sufficient storage volume.

Using small-scale storage features requires the control of relatively low flows. The most effective way of doing this is to keep the head of water in the system low (ie the height of water above the orifice level) so that the orifice opening can be as large as possible. Orifice diameters as small as 15 mm can be acceptable provided that the opening is well protected from material that could potentially cause a blockage (eg by placing the orifice downstream of pervious surfaces or a suitable, cleanable filter). Guidance is provided in **Chapter 28**. Surface weirs can also be used to control flows from surface features or along sloping conveyance systems as shown in **Figure 10.13**.

10.2.3 Water quantity criterion 4: Preserve and protect hydrological systems

Natural hydrological systems in existing urban environments will often have been damaged, culverted, polluted or otherwise degraded. Redevelopment or infill development in urban areas can provide opportunities to rehabilitate, protect and enhance these systems. Where the surface water management system for the site can make a positive contribution to natural hydrological systems, this should be an important design consideration.

Where practicable, consideration should be given to whether watercourses flowing through culverts within urban areas can be returned to open channels with all the concomitant water quantity, water quality, amenity and biodiversity benefits associated with surface systems. Runoff from the pre-development site may have been of poor quality, but sediment and pollutant loadings can be significantly reduced by treating the runoff using SuDS. Hydraulic control of the runoff will also help reduce erosion, morphological damage and local flooding. Where existing hydrological features provide valuable local planting, habitats and biodiversity, these should be preserved and enhanced by the SuDS wherever possible.

Existing urban areas may have highly compacted soils that are effectively impermeable to water. Where possible and appropriate, opportunities should be taken to rehabilitate surface soils to promote infiltration.

10.2.4 Water quantity criteria 5 and 6: Drain the site effectively and manage on-site flood risk

Exceedance flows (ie flows in excess of those for which the system is designed) should be managed safely in above-ground space such that risks to people and property are acceptable. Definitions of acceptable risk should be sought from the local planning authority. Where space is limited, this often means directing excess flows into roads. Safe storage zones and conveyance channels for extreme events can be included as part of road or car park designs using raised kerbing or speed bumps as containment features. Civic spaces, such as pocket parks, squares and plazas, can also be designed to function as exceedance storage zones (Figure 10.14).

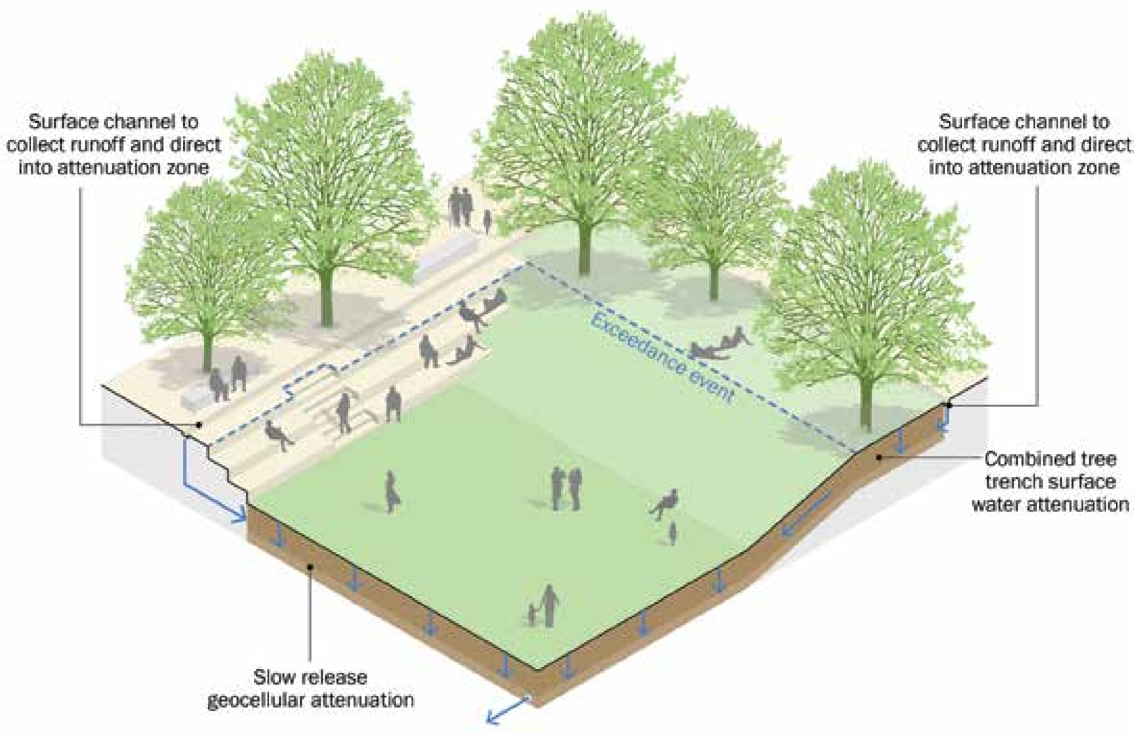


Figure 10.14 Multi-functional civic space

SuDS and exceedance flow management can form key design elements of linked blue and green corridors as well as squares and public open areas. In Rotterdam, for example, retrofit public plazas are used as excess runoff storage areas several times a year and as recreational areas at other times, as illustrated in Figure 10.15. Some of these include green space, whereas others are paved to provide sports facilities.

▶ See the Benthemplein Water Square case study in Section 10.4.

(a) during recreational use (courtesy Jeroen Musch)

(b) storing excess surface water runoff (courtesy De Urbanisten)

Figure 10.15 Benthemplein Water Square, Rotterdam

Where SuDS discharge into a sewer (Section 10.2.2), the effect of water levels in the downstream sewer on the operation of the SuDS should be considered. On many sites extra storage is required to reduce the risk of site flooding when the downstream sewerage system is full and does not have sufficient capacity to drain the site. Flap valves may also be required to prevent water from the sewer backing up and flooding the site.

10.2.5 Water quality criterion 1: Support the management of water quality in receiving surface waters and groundwaters

Runoff from roof surfaces within urban areas and runoff from pedestrian areas will require limited treatment. Any surface that has vehicular use, however, will need to demonstrate that the proposed treatment system is suitable to minimise risks to the receiving environment.

Treatment is normally achievable using soil or gravel filtration media systems (eg pervious pavement, tree pits, bioretention systems) or through the use of planted conveyance and storage zones (eg swales, wetlands/ponds). Where, due to space constraints, the surface water management system has to remain largely beneath the surface, then proprietary treatment products may prove to be the most viable option.

- ▶ Guidance on the design of SuDS for treatment is provided in Chapter 26.

10.2.6 Amenity criterion 1: Maximise multi-functionality

Section 10.1.3 discusses how designers should seek out every available space for SuDS. Designers should also consider how that space can perform multiple functions. In urban areas, where the density and impermeability of the development is high, this becomes particularly important and is best achieved through collaboration (Section 10.1.1).

SuDS should be integrated into urban areas to ensure that competing requirements are managed, and the urban landscape is 'hard-working', that is it performs multiple tasks and provides multiple benefits from even the smallest land-take. SuDS in urban areas should be considered alongside provision of green infrastructure, delivery of biodiversity objectives and the creation of community amenities to support urban lifestyle and function, where necessary finding a balance between competing needs.

Rain gardens/bioretention areas are an excellent example of how SuDS components can be integrated into a streetscape with limited impact on the primary purpose of an urban space. They can be integrated into a wide range of street features, such as on-street parking, pedestrian crossing points, spaces for cycle storage, cycle hire stations and seating areas. They can also be used to assist traffic calming measures, including gateways and build-outs.

- ▶ Guidance on the design of rain gardens is provided in Chapter 18.

Pervious pavement is another important example of where hard surfacing for pedestrian, recreation or vehicular use can be used for surface water management with limited impact on the primary purpose of an urban space.

▶ Guidance on the design of permeable paving is provided in **Chapter 20**.

▶ See **Typology 2: medium residential infill** in **Section 10.3**.

In particularly dense developments, where green space is minimal or may be completely absent, every hard surface becomes a rainwater collector and every construction profile should be considered in terms of its contribution to and potential for management of surface water runoff. Hard surfaces associated with parking, footways and podiums can attenuate runoff, communal areas can accommodate rain event water features and green roofs can be integrated to slow the runoff rates (**Figure 10.17** in **Section 10.3**). For further information.

▶ See **Typology 3: mixed use** and **Typology 6: elevated spaces**

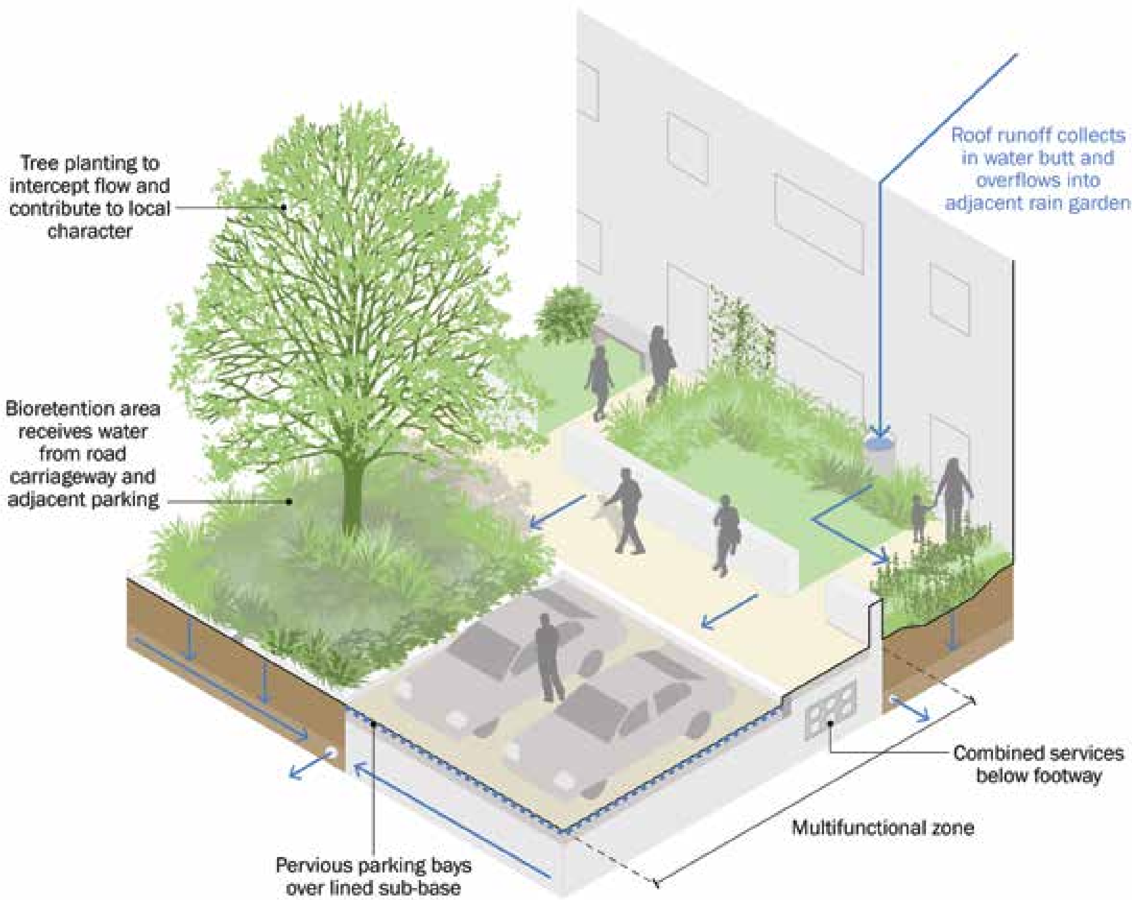


Figure 10.16 Multi-functional streetscape

10.2.7 Amenity criterion 2: Enhance visual character

SuDS design can play a significant role in enhancing the visual character of the urban environment, which in turn contributes to multiple amenity benefits, as discussed in **Chapter 5**.

Within high-density urban environments, the quality of the detailing is very important as part of the overall visual character for the site. These locations tend to have high footfall, so the detailing can have an impact on a large number of people (both residents and visitors) and it is often seen close up. There can also be constraints on ensuring that the design fits in with existing built form and planning expectations.

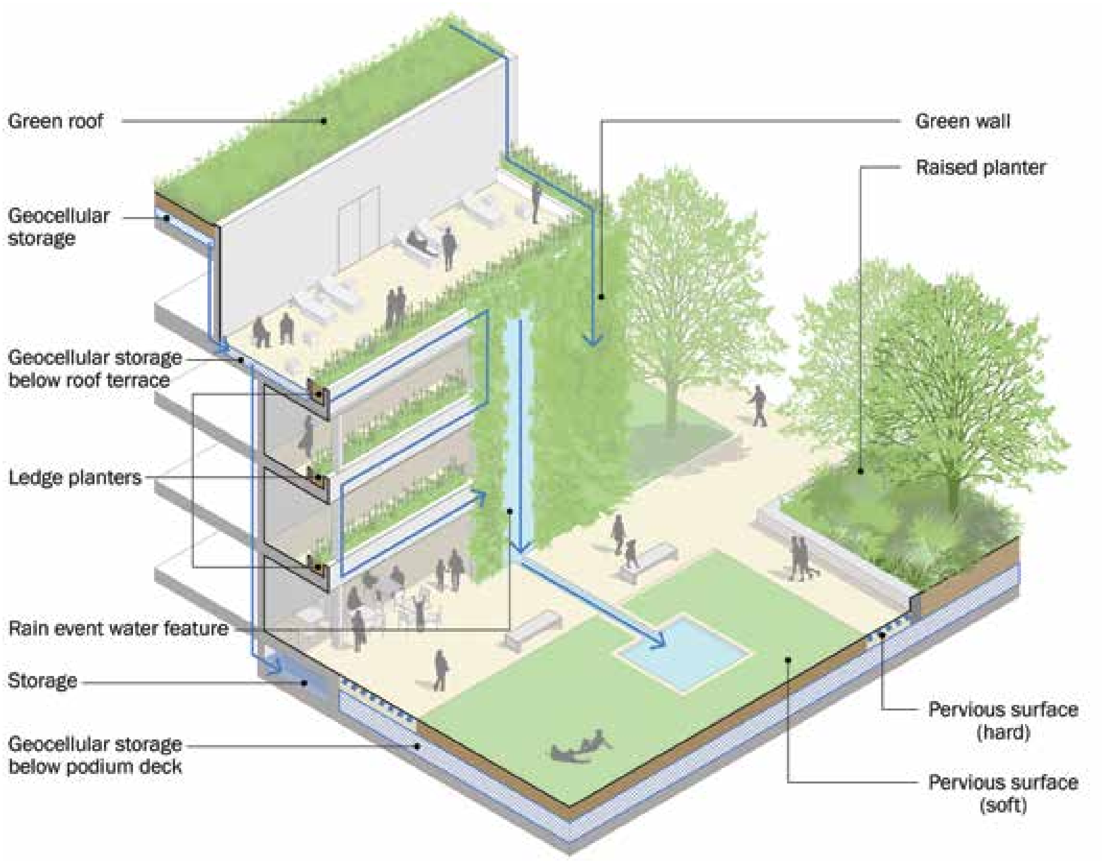


Figure 10.17 Multi-functional use of elevated spaces

It is important that SuDS design is sensitive to the historic environment. This involves considering the existing character and materials to ensure that the proposals retain and enhance the historic setting. It also requires high-quality (and often subtle) detailing and finishes.

In some cases, SuDS already form part of the heritage of the area, such as the roadside rills in Cambridge (**Figure 10.18**).

Examples of opportunities for SuDS implementation in historic environments include:

- the use of permeable paving to enhance public open space while controlling and treating runoff
- the incorporation of green roofs onto modern extensions to historic buildings or in new developments or extensions in conservation areas
- the implementation of sensitively designed water butts and/or rainwater harvesting systems adjacent to or within historic buildings
- the use of surface rills that reflect the existing historic character within historic hardscape areas.

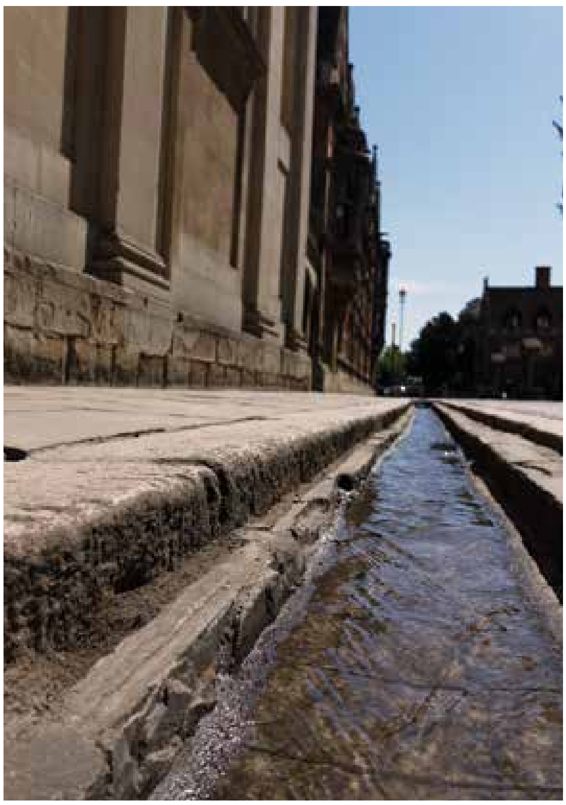


Figure 10.18 Roadside rills, Cambridge (courtesy Cambridgeshire County Council)

The use of landscape features for storing surface water runoff will require consideration of the impact on any trees in the vicinity and on any other landscape features of historic importance. Where infiltration is proposed, this also needs to ensure that it does not undermine historic buildings or archaeology.

The designation of a conservation area does not mean that new development is prohibited, but it does mean that any new development should make a positive contribution to the conservation area. Therefore, good design and detailing, with due regard to the use of materials, existing green (and blue) spaces, sight lines etc should meet the conservation area requirements.

Under the permitted development order, a council can make Article 4 (1 and 2) directions that withdraw 'permitted development' rights, which can affect existing features such as fence lines and trees. In sensitive locations it is, therefore, advisable to consult the development control section of the LPA to ascertain whether the work is permitted development and for advice on appropriate materials and design.

For listed buildings any external changes or additions required by SuDS need to be permitted by the local planning department, who may consult the relevant statutory authority (English Heritage, Cadw, Historic Scotland or NIEA). For grade 1 listing, any internal changes or additions will also need listed building consent. As with conservation areas, any proposal should retain and enhance the reason for listing, which means that consideration of materials and composition is important.

10.2.8 Amenity criterion 3: Deliver safe surface water management systems

The function and access requirements of the urban space should also be considered when designing SuDS schemes. The risks to health and safety associated with the SuDS scheme should be assessed during the early stages of the project and continually reviewed and reduced during the course of the project.

Considerations for safety when designing urban SuDS include the following:

- Edge conditions and fall protection need to be considered at an early stage to prevent later additions of barriers, which may clutter the landscape and prove detrimental to the overall character of the area.
- When designing SuDS with open water, the location, water depth and edge detail should be considered to protect the safety of users and workers. This does not discount their inclusion, but highlights the need to design out risk and to consult relevant groups to ensure that the end product is fit for purpose.
- In tight urban spaces, shallow gradients may not be achievable and/or capacity requirements may call for steeper gradients. In such cases, reinforced steeper gradients and hard edges may provide a solution. If so, the edge detail needs to be considered to promote the safety of users and workers – to prevent falls. Detailed paving, wide edge details with contrasting colours and planting can all promote a safe barrier-free landscape. For ground level features that are close to houses, schools or along busy pedestrian areas it may be best to use features that are normally dry with subsurface flow. In extreme events the water could be allowed to rise and gradually drain away.
- Runoff entering permanent water features should be treated by at least one treatment stage before discharge into the feature to minimise health risks (**Chapter 26**).
- Planting within any SuDS component needs to retain sightlines and avoid hidden or heavily shaded spaces, such as raising tree canopies to ensure that people can walk beneath them and see through them. The maintenance of sightlines is vital to ensure that vehicles can be manoeuvred safely and that all signage is visible. This also provides a degree of natural observation within the public realm and allows individuals to assess their personal security (see below).
- Opportunities for crime reduction should be identified by adopting the 'secure by design' approach, achieved by crime prevention through environmental design (CPTED).
- The location and/or load-bearing capacity of SuDS components should be reviewed to ensure that other features, such as building facades, can be maintained and accessed safely.

▶ Reference should be made to the health and safety checklist provided in **Appendix B**.

10.2.9 Amenity criterion 4: Support development resilience/adaptability to future change

Urban spaces are always changing, as they adapt to the community they serve, advancements in technology and the unavoidable deterioration of physical features. For instance, street furniture and lamps may need replacing within a decade; hard surfaces often need repairing or replacing due to wear every other decade, or reinstating after below-ground works; there can be shifts in the needs for public and private transport; and there may even be changes in surface water runoff characteristics due to climate change or increased development within the SuDS catchment area. This means that there may be a need to upgrade as well as maintain the functionality of the SuDS scheme, while also being mindful of the evolving design and function of the urban space. These changes or upgrades may provide additional or new opportunities for SuDS.

In order to prevent inappropriate interventions or loss of key SuDS components within a scheme, it is important that stakeholders understand the roles of different components, particularly if there are components on their land. Therefore, consideration should be given to finding ways to embed knowledge within the community and to ensure that this knowledge is retained over the long term. Providing signage and making the scheme legible (see **Amenity design criterion 5, Chapter 5**) will contribute to this. Listing the components on an asset register can also be beneficial, and is mandatory for some developments.

It is important to take account of repair and replacement needs of SuDS components, recognising that different elements of a SuDS component can have different durability levels. Where SuDS components (or elements of a SuDS component) have a shorter design life than the SuDS scheme as a whole, the design should take into consideration how they will be replaced to retain the functionality of the scheme (**Chapter 35**). Planters, rills, channels and kerb stones can be designed as simple units to enable repositioning, alterations, adaptations and improvements over time.

Retrofitted SuDS should ensure that street surfaces retain good access to all underground services. Wherever possible, services should be located in specific service corridors that are surfaced with normal construction. Some services may end up below the pervious surface, and the backfill to the trench should be specified so that it cannot be washed out by infiltrating water. Consideration also needs to be given to reinstatement requirements for statutory undertakers.

10.2.10 Amenity criterion 6: Support community environmental learning

The opportunities for deriving benefits from SuDS relating to environmental learning will often be greater in urban settings. A green or blue biodiverse feature (either in a streetscape, public area or on an accessible roof) is likely to be unusual and therefore of particular interest and value for local community environment groups, schools and visitors/tourists (**Section 5.2.7**).

10.3 DIFFERENT URBAN DEVELOPMENT TYPOLOGIES

A set of typologies has been developed to represent a range of urban conditions and to demonstrate the opportunities for integrating SuDS into their design. These typologies are **not** intended to be comprehensive; they are solely illustrative. The illustrations for each typology should **not** be followed rigidly. The illustrations are **simplified** representations of abstracted urban conditions aimed at showing how an integrated design might be achieved. The connections between SuDS components are indicated in a simplified form, as fully designed connections would be too complicated to show on these schematics. For each typology there will be a range of other potential surface water management solutions.

These ideas should be developed, enhanced and moulded to individual sites and budgets, so that they work with the specific opportunities and constraints of the site and fit in with the local character, while delivering as many benefits as possible.

Each typology includes a range of SuDS components that can be delivered individually or in combination. Not all real-life schemes will be able to include all of the SuDS components shown for that particular typology. Equally SuDS components that are not shown are not discounted from any particular typology.

The preferred SuDS scheme for any site (whether it is one of the typologies presented here or not) will depend on strategic objectives for surface water management and the characteristics of the site and proposed development.

- ▶ Guidance on the SuDS design process is provided in **Chapter 7**.
- ▶ For guidance on how to design individual SuDS components see **Chapters 11–23**.

All the typologies are designed to apply primarily to new infill developments within existing urban conurbations. However, the majority of SuDS components shown could equally be retrofit to existing urban development.

The site for each typology is assumed to have the following characteristics:

- not suitable for infiltration
- free from contamination

These characteristics are not necessarily representative of all sites within existing urban areas.

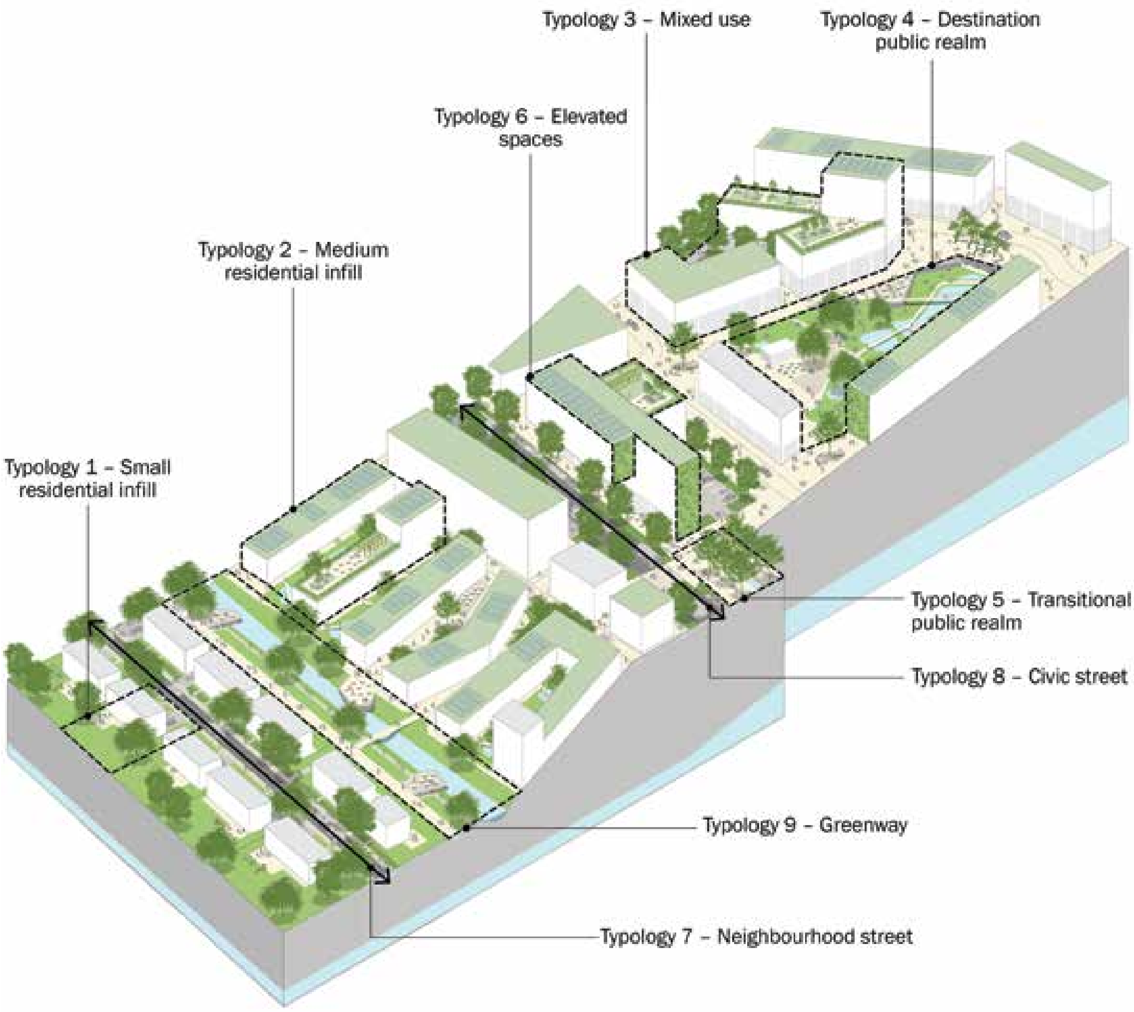


Figure 10.19 Typologies within the urban landscape

Figure 10.19 illustrates how these different typologies can coexist within the urban landscape.

Summaries of the typologies are provided here.

Typology 1 – Small residential infill

Low-density housing of detached and semi-detached dwellings. Typically this type of housing is located on sites with moderate space availability, which allow front and rear gardens, on-street public parking and off-street private parking, along with clear boundaries between public and private land. It is also assumed that these are relatively high value properties, based on the land-take within an urban setting.

Typology 2 – Medium residential infill

Medium-density housing development of apartments and maisonette style dwellings, typically low rise over two to three floors. The development is assumed to have combined utilities and services along with community gardens and limited on-street parking.

Typology 3 – Mixed use

Mixed-use development within moderate to high-density inner city location. Assumed to have retail and/or commercial space at lower levels beneath upper level residential apartments and private residential amenities deck/garden. Assumed to have public realm interfaces, surface and basement parking provision and associated servicing and access requirements.

Typology 4 – Destination public realm

An inner city space that provides a community focus, event areas and social function. These spaces can be hard paved squares and plazas or softer spaces associated with urban greening. Either way they are required to be flexible to accommodate the urban social calendar and variable numbers of people.

Typology 5 – Transitional public realm

An inner city space that is dominated by access requirements and confined by the existing built form. The design and SuDS opportunities of these spaces can often be challenging. Therefore this typology aims to provide ideas and insights to enable efficient and effective integration of SuDS in even the smallest urban spaces.

Typology 6 – Elevated spaces

This typology explores design of urban SuDS above ground level, from green walls and green roofs to amenity podium decks associated with residential and mixed-use developments.

Typology 7 – Neighbourhood street

Inner city streets that act as a local road or main road into residential areas, often with restricted space availability within existing built form and infrastructure. Residential neighbourhoods require a streetscape that may require parking provision, public transport links, ease of access into dwellings, servicing and trash collection, clear land ownership between public/private, along with adequate setbacks for privacy and regulation.

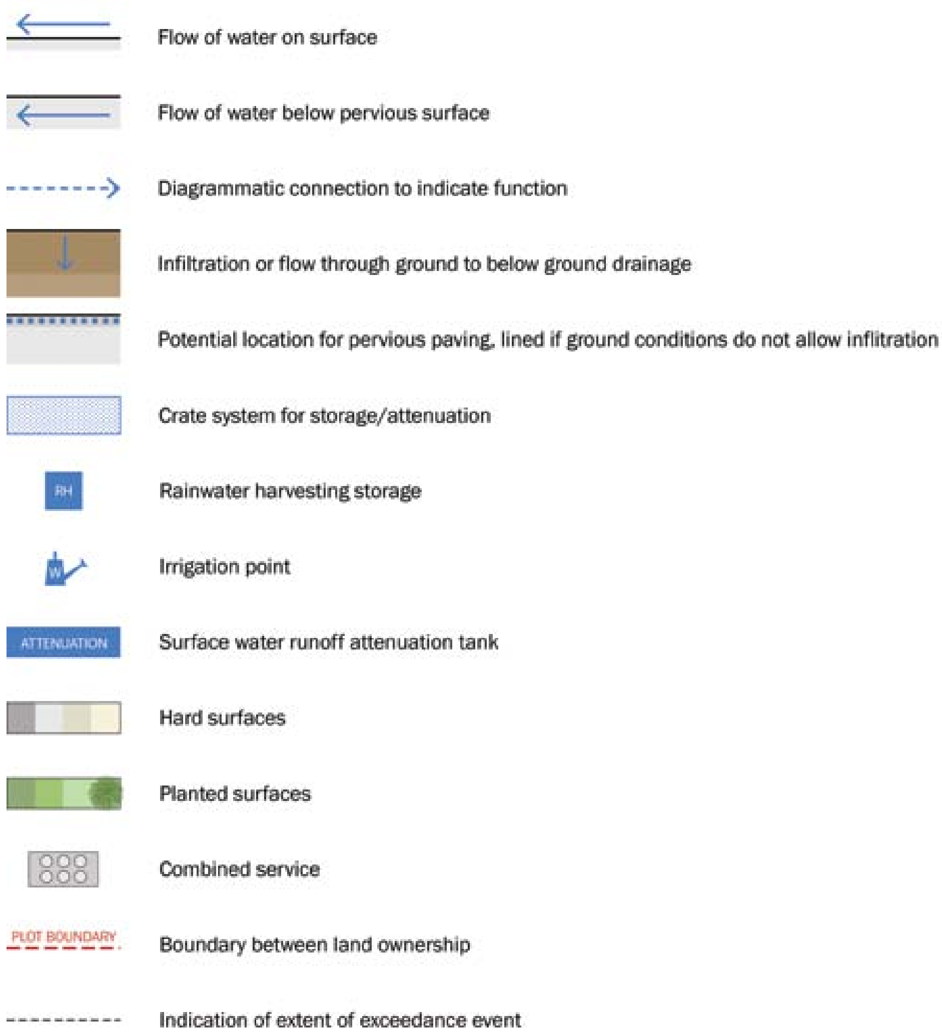
Typology 8 – Civic street

Inner city streets that have a community function and focus within a commercial setting. These streets often have changing characters, one day a retail street and the next market stalls and pop-up cafes. This typology demonstrates how SuDS can be integrated into these flexible civic spaces.

Typology 9 – Greenway

Inner city green corridors and disused historic infrastructure routes that become key pedestrian and cycle routes, connecting the city away from built-up areas, traffic and crowds. These spaces provide valuable social and biodiverse landscapes as well as connective green infrastructure, while forming an important part of the urban SuDS strategy.

The following key should be used for all figures provided for the typologies:



Typology 1 – Small residential infill

Low density housing of detached and semi-detached dwellings. Typically this type of housing is located on sites with moderate space availability, which allow front and rear gardens, on-street public parking and off-street private parking, along with clear boundaries between public and private land. It is also assumed that these are relatively high value properties, based on the land-take within an urban setting.

Design approach

Small residential infill should take advantage of the space allocated to each plot, providing SuDS components that would often not be feasible in denser residential developments. All SuDS design should also aim to enhance and promote local character to optimise land value and neighbourhood desirability.

Considerations

Whether retrofit or new build, each plot should ideally be able to attenuate and treat its own runoff with on-plot SuDS components. However, with impermeable conditions and confined sites this may not be feasible, but runoff rates can still be reduced.

For new build, it should also be a design ethos to combine components as part of a neighbourhood-wide strategy. This approach should take into consideration the shared spaces and streetscape to enable greater consideration of scale, which helps with managing exceedance events and provides informal community spaces. The local highway authority would need to be consulted in these scenarios.

Integrating SuDS components such as bioretention systems with strategic tree planting and underdrained swales can aid the creation of leafy green streets, which in turn can support higher land/property values. To achieve this, the width of streetscape needs to be considered at the early design stages (see **Typology 7** for further information).

With a neighbourhood-wide approach, the ownership and maintenance of SuDS need consideration, as some components may cross over plot boundaries and highway boundaries.

Potential SuDS components

- Rainwater harvesting systems overflow into on-plot rain gardens.
- Green roofs over the garage overflow into driveway attenuation.
- Shared driveways and patios are drained using lined pervious pavements with sub-base storage.
- Rain gardens and sub-base storage slowly drain into underdrained swales and bioretention areas in highways.
- The public footpath is drained into an underdrained swale which may also collect outflow from the on-plot SuDS components.
- The public highway is drained with a single drainage profile into a bioretention area that incorporates tree planting. The bioretention area integrates pervious on-street parking and access into driveways.
- The underdrained swale and the bioretention area convey water into a local detention basin if space is available.
- The green roofs, rain gardens, underdrained swale and the bioretention area all play an important role in treating surface water runoff.

Multiple benefits

- The underdrained swale and on-plot rain gardens provide a privacy strip along the property frontages.
- Biodiversity is supported by the on-plot green roofs and rain gardens, along with the public highway swales and bioretention areas with tree planting.
- Visual quality of the streetscape is enhanced with the provision of leafy green streets.

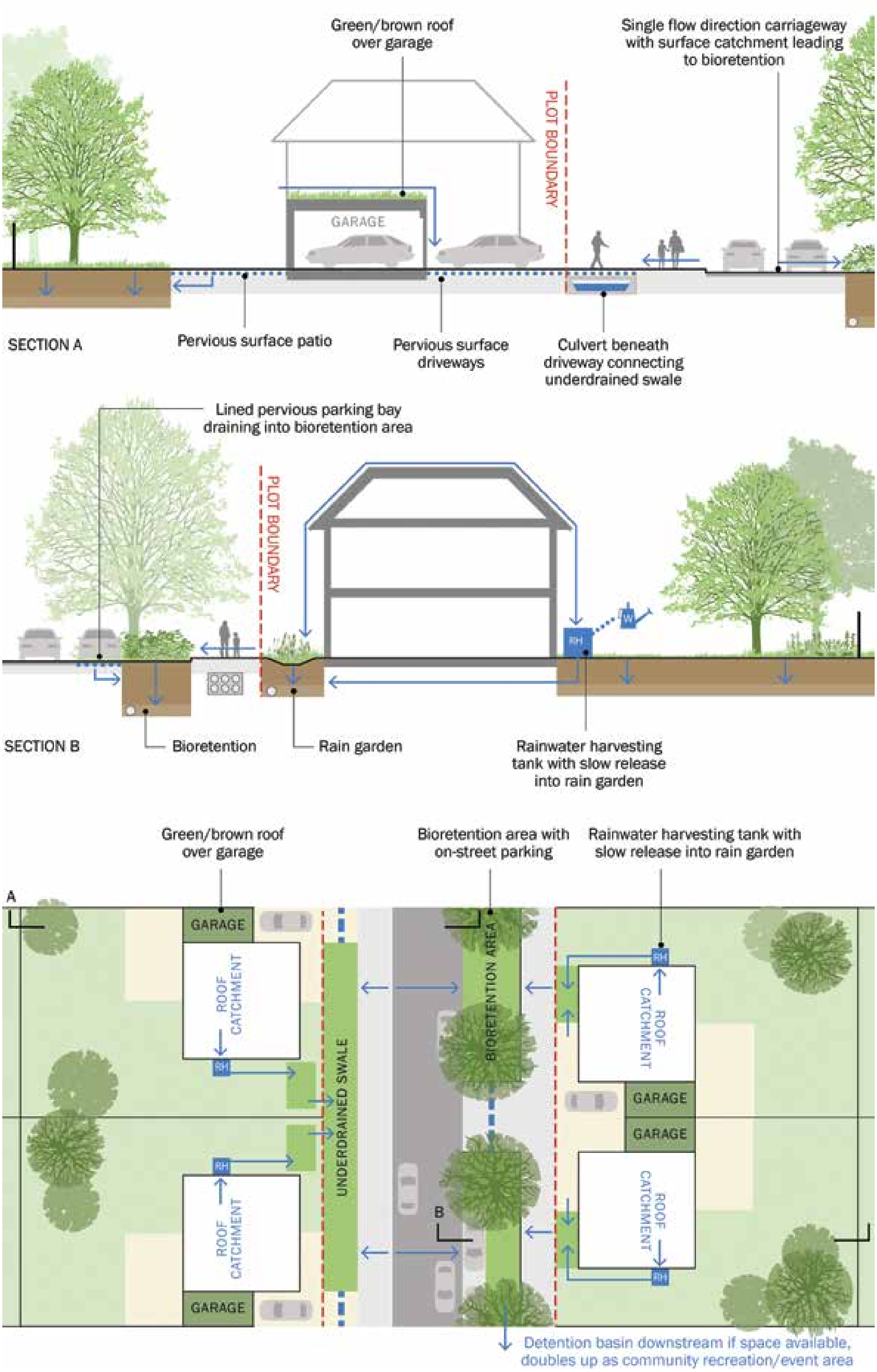


Figure 10.20 Typology 1 – Small residential infill

Typology 2 – Medium residential infill

Medium density housing development of apartments and maisonette style dwellings, typically low rise over two to three floors. The development is assumed to have combined utilities and services along with community gardens and limited on-street parking.

Design approach

Residential infill projects should deliver multiple benefits from good urban design and SuDS. This will embed SuDS components and support a range of amenities and services required by the community. SuDS in compact new-build residential areas should therefore give consideration to access, service routes, utilities, green infrastructure, biodiversity and community facilities such as outdoor dining areas, seating provision and productive zones.

Considerations

Measures can be small and simple with minimal investment, such as rain gardens, or more complex with greater investment, such as below-ground storage tanks. Even the simplest surface water management techniques are beneficial, but systems with greater diversity are inherently more adaptable to the changing urban climate. The ambition should therefore be to provide a range of SuDS components within a site-wide surface water management system.

Potential SuDS components

- Rainwater harvesting (integrated into roof level), green roofs and terraces attenuate roof runoff and overflow into below-ground storage tanks within communal areas.
- Hard surfaces are drained using pervious pavements with sub-base storage, which discharge into adjacent bioretention systems and trench planters.
- Bioretention systems and trench planters convey, attenuate and treat surface water, slowly discharging into a local detention basin if space is available.
- The vehicle carriageway is drained with an inverted drainage profile with surface catchment channels that discharge into a local detention basin (if space is available) or the local drainage system.
- The green roofs, planted trenches and bioretention systems all play an important role in treating surface water runoff.

Multiple benefits

- Stored water can be recirculated to tap points within the communal garden and within private courtyards and terraces for landscape maintenance and irrigation.
- The planted trenches provide a privacy strip along the property frontages to reaffirm personal boundaries and support urban greening.
- A communal garden provides outdoor recreation and gathering space.
- The private roof terraces and courtyards provide outdoor recreation and gathering spaces.
- Biodiversity is supported by the green roofs and communal gardens.
- Local amenities are enhanced with the provision of communal gardens.

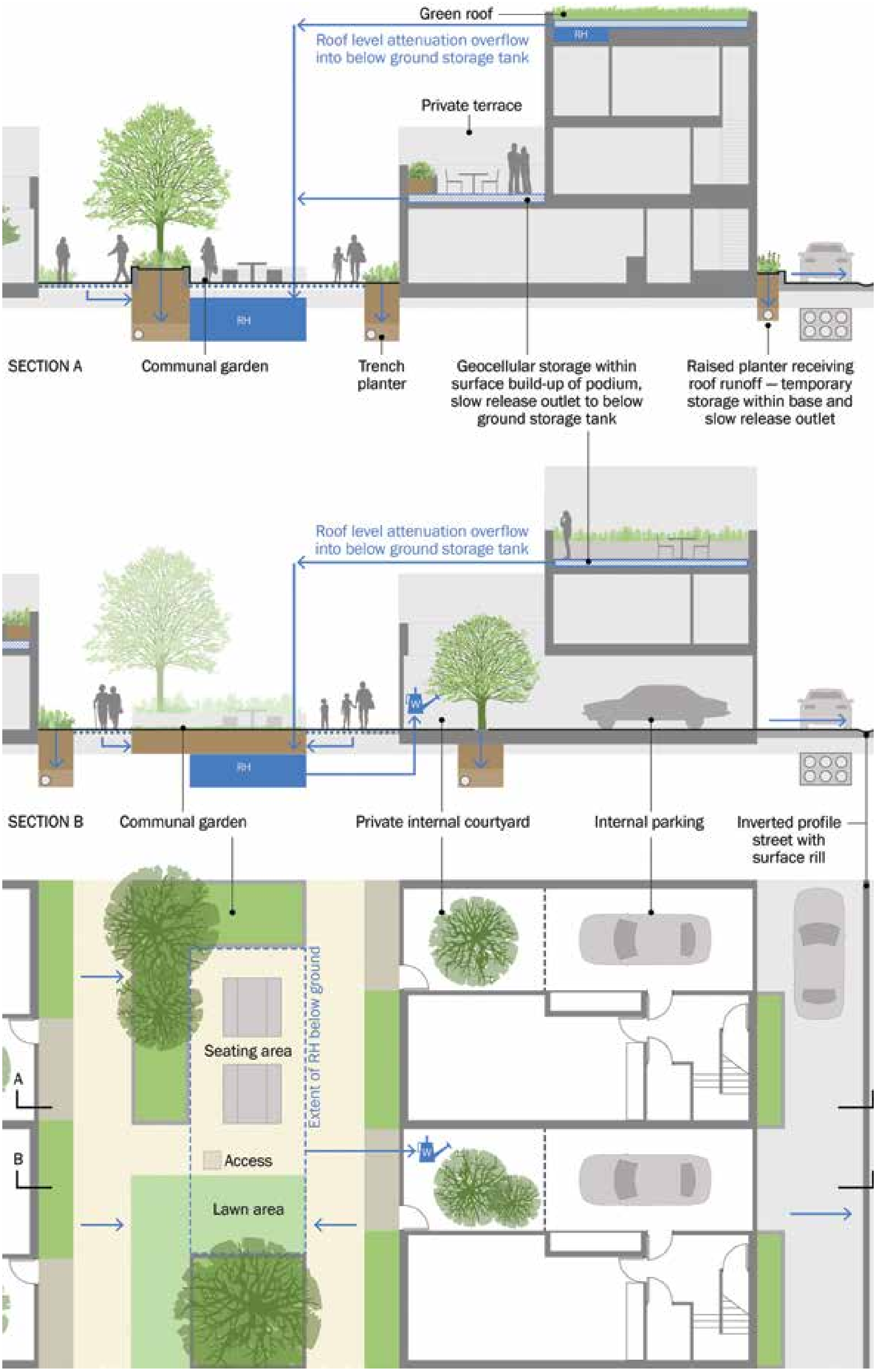


Figure 10.21 Typology 2 – Medium residential infill

Typology 3 – Mixed use

Mixed-use development within moderate to high density inner city location. Assumed to have retail and/or commercial space at lower levels beneath upper level residential apartments and private residential amenities deck/garden. Assumed to have public realm interfaces, surface and basement parking provision and associated servicing and access requirements.

Design approach

Mixed-use developments should take advantage of their scale and extent, providing SuDS components that would often not be feasible in smaller single use developments. Therefore, the approach to SuDS within mixed use development should start at a strategic level with site-wide consideration of economies of scale.

Considerations

The public boundary condition of a mixed use development is a key contributor to character and community engagement. Considering the SuDS as part of this condition will utilise the space efficiently while enhancing urban greening and streetscape quality.

Site services can be a dominant influence on layout and design. Requirements such as vehicle and pedestrian movement, building access, servicing, maintenance, utility routes, parking capacity, street furniture, green infrastructure and drainage all need to be established during the early design stages to ensure that the proposed scheme avoids conflicts with SuDS.

Mixed-use developments often require parking provision, and this space can almost always be utilised for SuDS. The layout and levels should be designed to maximise the potential for site-wide water management.

Amenity podium decks associated with residential and office developments provide an opportunity to store water and attenuate flow, while enhancing character and improve amenity provision. For further details refer to **Typology 6**.

With a site-wide approach the ownership and maintenance of SuDS needs consideration, as some SuDS components may cross boundaries.

Potential SuDS components

- Green roofs treat and attenuate runoff in their substrate and support root uptake with extensive planting. Geocellular storage layers can maximise the attenuation provided.
- Rainwater harvesting (integrated into roof/basement level) supports the buildings' non-potable water requirements (including residential, office and commercial).
- Green roofs overflow into the car park attenuation.
- Private terraces and communal amenity deck use pervious surfaces over geocellular storage layers (hard and soft) to attenuate roof runoff and overflow into parking area sub-base storage and boundary bioretention/detention areas.
- Car park is drained using pervious pavements with sub-base storage, which discharge into adjacent bioretention/detention areas.
- Exceedance event capacity is provided within the car park using high kerbs and level changes to temporarily retain water.
- Pedestrian circulation spaces are drained using pervious pavements with sub-base storage, which discharge into adjacent bioretention systems.
- Bioretention systems convey, attenuate and treat surface water, slowly discharging into a boundary detention basin, if space is available.

- The public highway is drained with a single drainage profile into a bioretention system that incorporates tree planting. The bioretention system integrates pervious on-street parking and access into drop-off.

Multiple benefits

- The bioretention systems located on the streets and car park can aid the definition of plot boundaries.
- The amenity deck associated with the residential development provides communal gardens.
- Biodiversity is supported by on-plot green roofs and planted terraces, car park bioretention systems and boundary detention areas, public highway tree planting and bioretention systems.
- Local character is enhanced with the provision of leafy green streets.

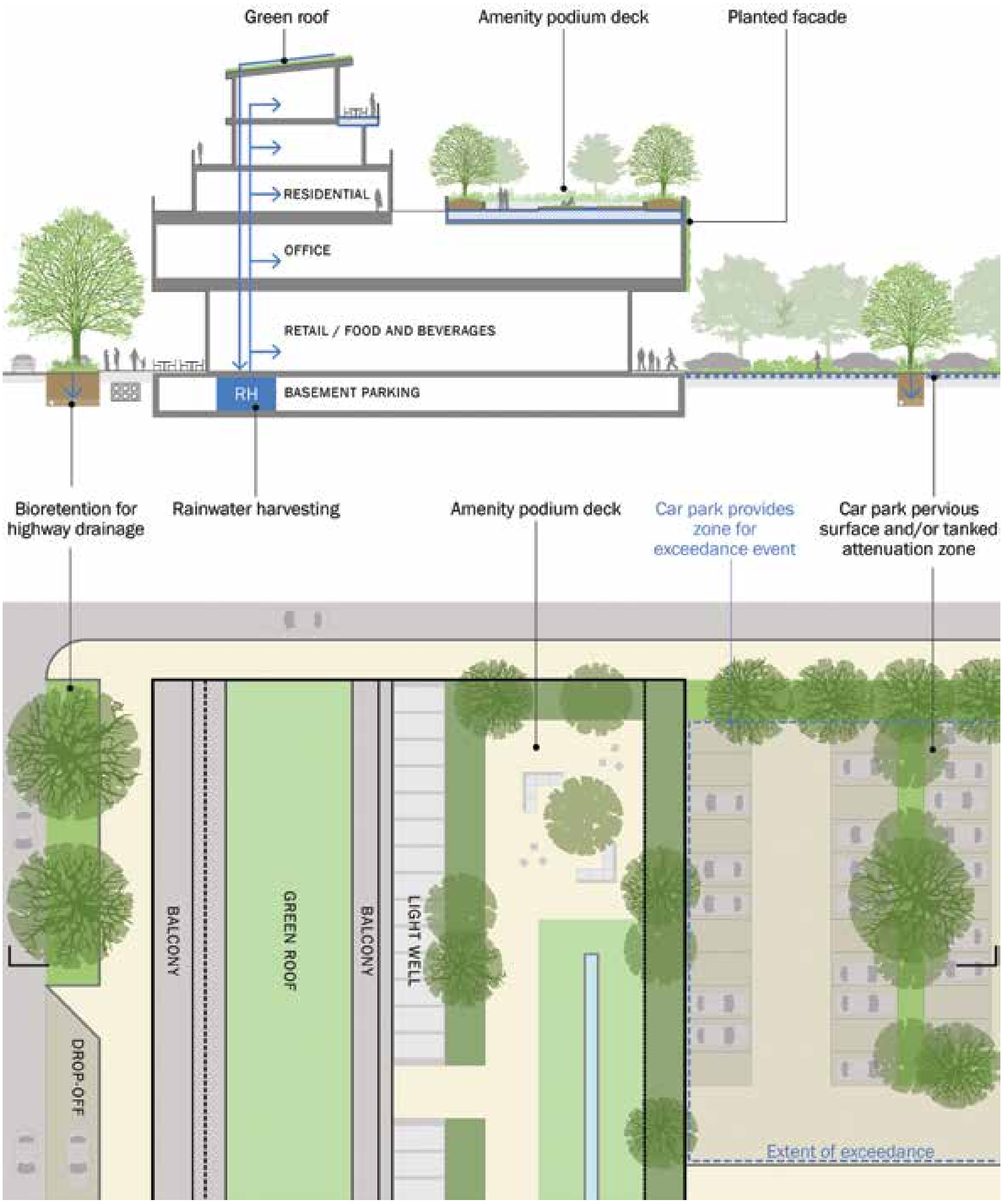


Figure 10.22 Typology 3 – Mixed use

Typology 4 – Destination public realm

An inner city space that provides a community focus, event areas and social function. These spaces can be hard paved squares and plazas or softer spaces associated with urban greening. Either way they are required to be flexible to accommodate the urban social calendar and variable numbers of people.

Design approach

Inner city pocket parks, squares and plazas create openings in the urban form that provide rare opportunities to collect and treat the surface water runoff from a wider area. To use the space efficiently, the design should aim to accommodate the social and functional needs of a community alongside the needs of SuDS.

Considerations

Before the design process can begin, a high-level review of the location's SuDS performance requirements (ie attenuation, storage, and treatment) is needed, as this will inform the design process.

Incorporating large-scale SuDS components into the public realm takes planning and consultation; it is important that the design process recognises the purpose of the new park/plaza, so that SuDS components do not conflict with that purpose, are integrated efficiently and are accepted by the local community.

SuDS components need to work with the functional requirements of the public realm, including: vehicle and pedestrian movement, building access, servicing, maintenance, utility routes, street parking, street furniture, green infrastructure and drainage.

Potential SuDS components

- During frequent rain events the surface water is collected and stored below the park's surface, slowly releasing into the existing local drainage system.
- During exceedance events the park provides a temporary storage area, which enables the surface water runoff to be gradually released into the local drainage system. The change in level that defines the area could be used to provide seating or a performance arena. An overflow that discharges to the local drainage system should be provided to set the maximum exceedance water level.
- The hard surfaces surrounding the central green space are drained using pervious pavements with sub-base storage, which discharge into the below-ground attenuation of the park.
- Adjacent roof catchments can be drained into the central space via the pervious pavements and combined tree trenches placed along the conveyance route to provide natural irrigation.

Multiple benefits

- The park provides a public green space with a distinct and dynamic character.
- The park can support local community events, promote a local identity and aid wayfinding through the creation of a landmark.
- The educational value can be maximised to inform users of the park's SuDS function, which they can witness themselves during exceedance events.
- Biodiversity is supported by the park's planting strategy, which could include a range of flora to suit the variable planting conditions.
- Accessibility is retained by incorporating combined tree trenches below hard surfaces.

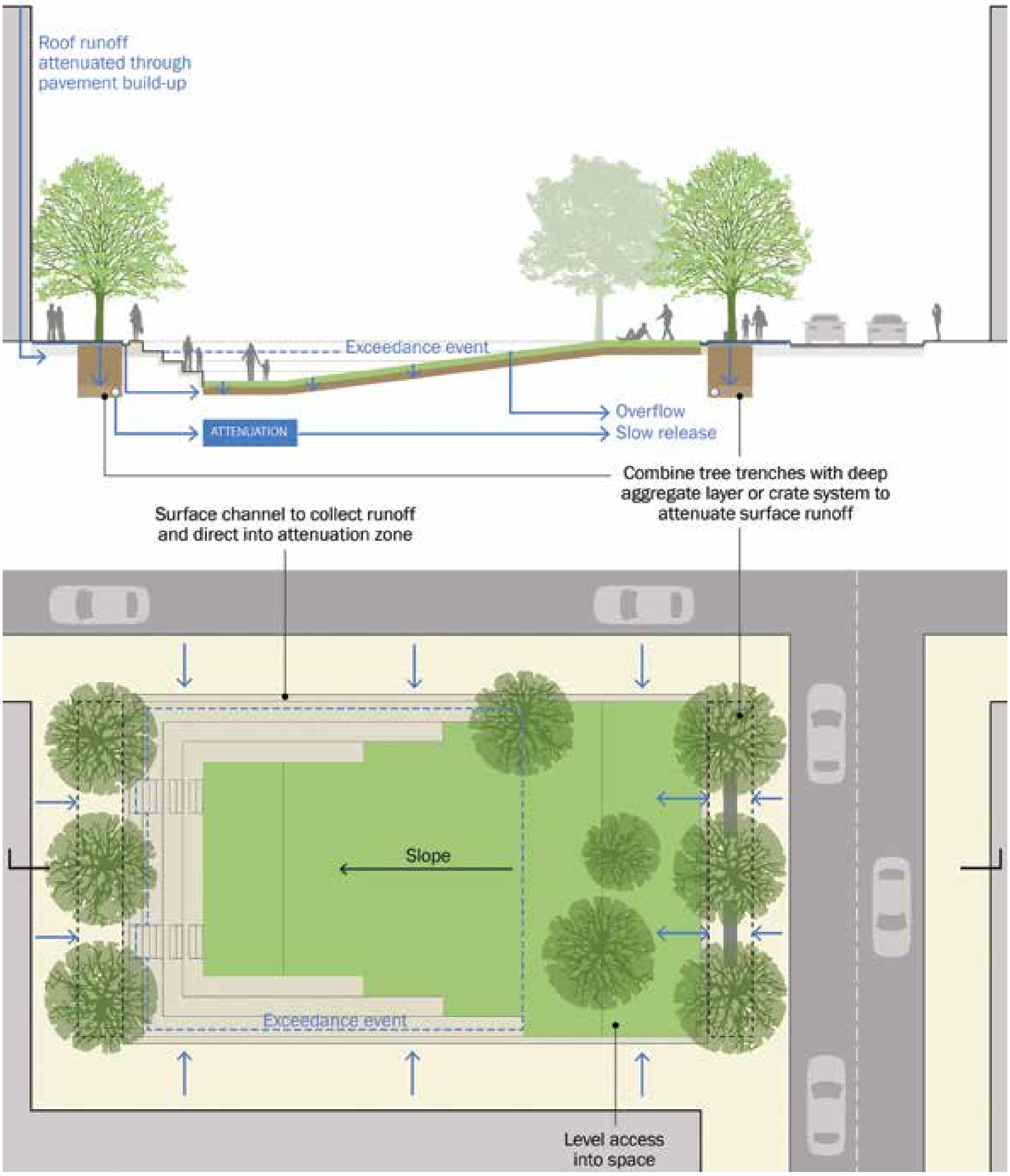


Figure 10.23 Typology 4 – Destination public realm

Typology 5 – Transitional public realm

An inner city space that is dominated by access requirements and confined by the existing built form. The design and SuDS opportunities of these spaces can often be challenging. Therefore, this typology aims to provide ideas and insights to enable efficient and effective integration of SuDS in even the smallest urban spaces.

Design approach

Within these transitional urban spaces, SuDS should be seen as a sequence of simple components that combine to form a site-wide strategy. Therefore, implementing what may seem a small gesture adds to the bigger picture to meet the attenuation and reduced runoff rate targets.

Considerations

Confined inner city spaces between buildings or major infrastructure often require complex access and circulation patterns. This inevitably results in extensive areas of hard surfaces that may also be heavily trafficked, which can limit the feasibility of some SuDS components. Pervious pavements and underground storage/attenuation are usually the most applicable methods in these scenarios, allowing people to move freely through a space with wall-to-wall hard surfaces. The below-ground attenuation can be just below the surface within the pavement build-up or deeper within large tanks and combined with tree pits/trenches. All systems can receive runoff from surfaces and adjacent roofscapes.

Opportunities to animate the public realm with SuDS components should be embraced, as this increases awareness and supports localised character. Animation can take many forms, including surface water features, sound sculptures linked to underground tanks, digital displays that show water movement and quantity, and other information sources about what is happening below ground.

Potential SuDS components

- The hard surfaces are drained using lined pervious pavements with sub-base storage, which discharge into the local drainage system or SuDS components further down the site-wide Management Train.
- During heavier frequent rain events the surface water is also collected via inverted drainage profiles leading to surface channels, which discharge into a defined zone to create a rain event water feature. This water feature slowly drains into the below-ground attenuation.
- During exceedance events, sunken features, such as seating areas, can provide a temporary storage area, which enables the surface water runoff to be gradually released into the local drainage system. An overflow that discharges to the local drainage system should be provided to set the maximum exceedance water level.
- Adjacent roof catchments can be drained into the space via the pervious pavements.
- Combined tree trenches placed along the conveyance route provide natural irrigation for the trees and attenuate runoff rates.

Multiple benefits

- Trees provide evapotranspiration, urban greening, shade and shelter, wildlife habitat and seasonality.
- The rain event water features provide a distinct and dynamic character.
- The space can promote a local identity and aid wayfinding through the creation of a landmark.
- The educational value can be maximised to inform users of the space's SuDS function, which they can witness themselves during regular rainfall events and exceedance events.
- Accessibility and the urban character is retained by incorporating combined tree trenches below hard surfaces.

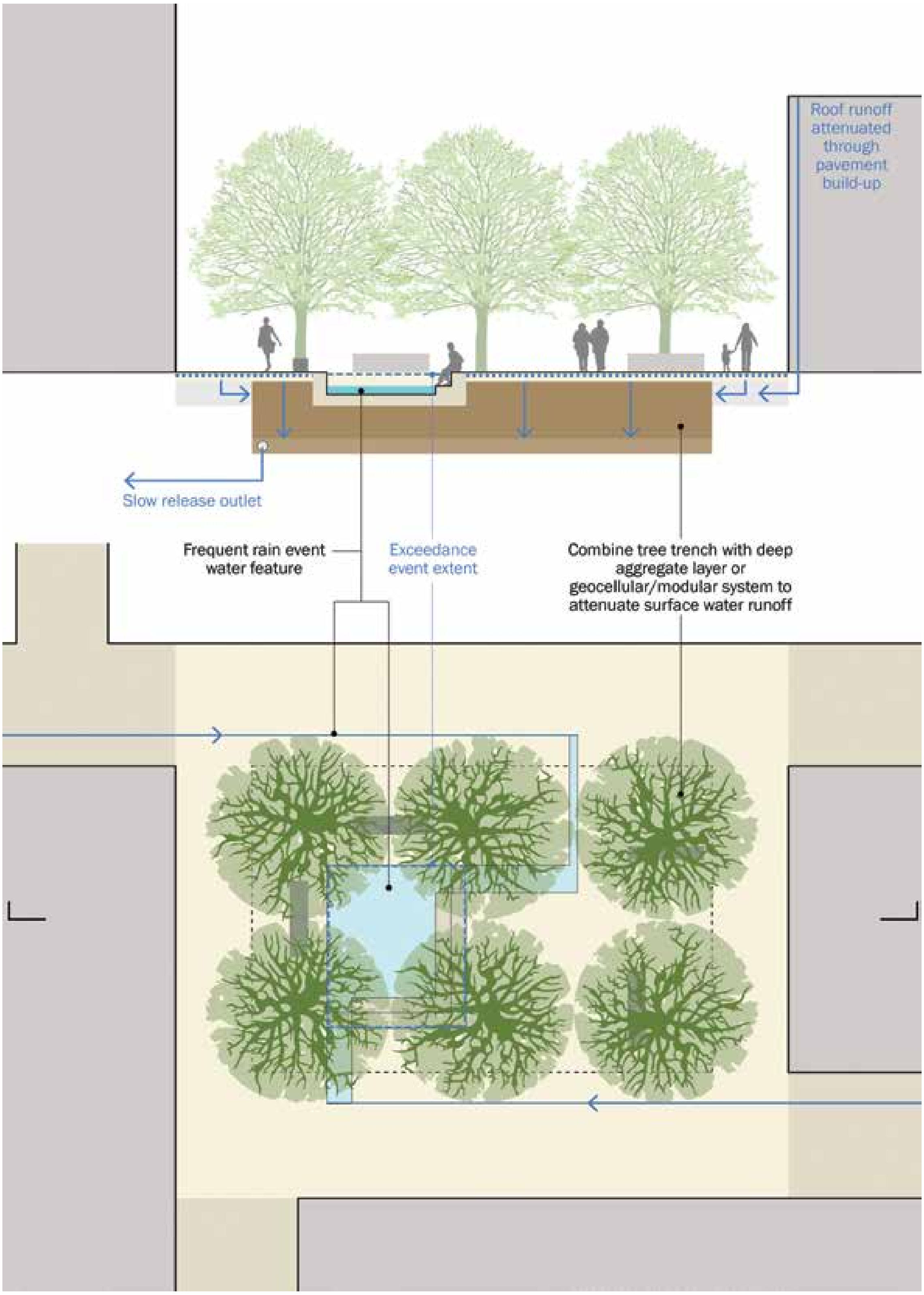


Figure 10.24 Typology 5 – Transitional public realm

Typology 6 – Elevated spaces

This typology explores design of urban SuDS above ground level, from green walls and green roofs to amenity podium decks associated with residential and mixed-use developments.

Design approach

Within high density urban developments elevated landscapes are key factors for the provision of private/semi-private outdoor spaces and urban greening. All urban projects should aim to use integrated SuDS components to provide opportunities to enhance character and amenity provision.

Considerations

Intensive and extensive green roofs can help reduce (and for frequent events often eliminate) the volume of runoff from the roof surface and, with suitable design, help slow runoff rates. Attenuation and treatment can then be delivered by incorporating further SuDS components into deck structures and planters.

SuDS within elevated landscapes have a series of considerations to ensure their functionality:

- The waterproofing of any substructure needs to be considered and co-ordinated.
- Potential loading of water, soil and the live load of plants needs to be calculated in all structural design.
- Future maintenance and management needs to be considered during the early design stages.
- Roof-level mechanical and electrical plant and penetrations can be combined with attenuation and storage components, but the extent of plant and penetrations needs to be reviewed to ensure efficiency of scale. Roof-level attenuation tends to remove the need for multiple deck penetrations and underslung pipework below podium decks.
- Biodiversity viability and value should be as important for elevated spaces as elsewhere, and needs to be considered when selecting plant species, optimising the habitat potential for the local flora and fauna.

Potential SuDS components

- Green roofs reduce runoff by storing water in their substrate and supporting root uptake and evapotranspiration with extensive planting. Geocellular storage or other drainage layers can maximise the attenuation provided.
- Green walls can also help reduce runoff volumes. However, consideration should always be given to the potential need for a supplementary supply of water other than from rainwater harvesting, which may mean they are not economic or environmentally acceptable solutions.
- Ledge planters can act as treatment biotopes, conveying rainwater from the roof to lower levels through granular fill and plant root zones.
- Roof terraces can be drained using pervious surfaces over geocellular storage, which discharge into downstream SuDS components.
- Podium decks can provide a large area of attenuation by using pervious surfaces (hard and soft) over geocellular storage, which discharge into downstream SuDS components.
- During heavier frequent rain events, runoff can be directed into rain event water features.

Multiple benefits

- Green roofs and green walls can help insulate buildings and reduce the urban heat island effect.
- Natural irrigation of green walls, can be supplemented with stored rainwater (from rainwater harvesting) in times of drought.
- Trees provide evapotranspiration, urban greening, shade and shelter, wildlife habitat and seasonality.

- The rain event water features provide a distinct and dynamic character, animating the space and increasing awareness of water.
- The educational value can be maximised to inform users of the space's SuDS function, which they can witness themselves during regular rainfall events.
- Irrigation supplies can be provided from rainwater harvesting tanks located at roof/podium level.

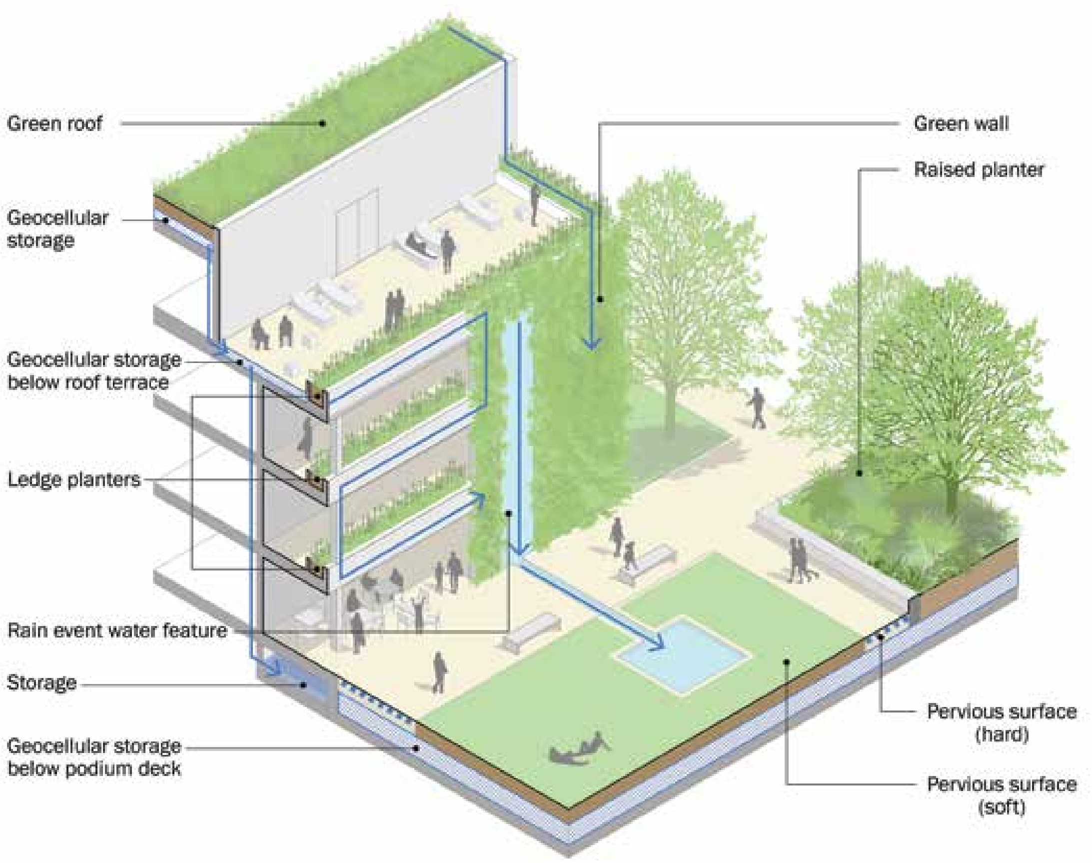


Figure 10.25 Typology 6 – Elevated spaces

Typology 7 – Neighbourhood street

Urban streets that act as a local road or main road into residential areas, often with restricted space availability within the existing built form and infrastructure. Residential neighbourhoods require a streetscape that may contain: public transport links; parking provision; ease of access into dwellings; servicing and trash collection; clear land ownership between public/private; along with adequate setbacks for privacy and regulation.

Design approach

The design of SuDS should focus on space efficiency and consistency to meet the functional and aesthetic demands of the streetscape.

Considerations

Simply providing the minimum space for carriageway and footway is not usually enough to support a sustainable urban design with integrated SuDS. During the master planning stages of a project, the street width needs to be realistic, that is wide enough to accommodate all the functions needed to support vehicle and pedestrian movement, building access, servicing, maintenance, utility routes, street parking, street furniture, green infrastructure and drainage. The dimensions of these elements will vary.

New-build streetscape should aim to include a linear element that acts as a multi-functional zone, combining parking, crossing points, traffic calming, green infrastructure, rain gardens, combined utility route and pedestrian footways. The width of this linear element is defined by the parking provision (parallel or perpendicular with the road) and the footway width. Filter strips and swales can also be incorporated, although they do require wider areas which need consideration during the master planning process.

Streetscape is often composed of public and private land, for instance in this typology public highway with footpath and private front gardens. Therefore when designing SuDS in the streetscape a door-to-door approach should be adopted to ensure that the space is fully utilised. For this typology, plot boundaries are clearly defined by building and fence lines, but the SuDS elements will need to flow across the boundaries.

Potential SuDS components

- Rainwater harvesting components overflow into on-plot rain gardens.
- Shared driveways and footpaths are drained using lined pervious pavements with sub-base storage.
- Rain gardens and sub-base storage slowly drain into highways trench planters, underdrained swales and/or bioretention systems.
- Trench planters collect, convey and treat runoff from adjacent footways and potentially roof catchment via downpipes. These can take the form of ground-level planted channels and/or raised planters.
- The public footpath is drained using lined pervious pavements with sub-base storage which discharge into the trench planters or bioretention systems.
- The public highway is drained with a single drainage profile into a bioretention system that incorporates tree planting and integrates pervious on-street parking and access into driveways.
- The trench planter and the bioretention system convey water into a local detention basin if space is available or the local drainage system.
- The trench planters and bioretention system with tree pits play an important role in treating surface water runoff.

Multiple benefits

- Multi-functional zones use space efficiently by combining street trees, on-street parking provision, footway, pedestrian crossing points, spaces for cycle storage, seating area etc. They can also be used to assist the traffic calming strategy through the creation of gateways that narrow the street width and therefore slow traffic speed.

- The trench planters and on-plot rain gardens provide a privacy strip along the property frontages.
- Biodiversity is supported by the on-plot rain gardens, along with the public highway trench planters and bioretention systems with tree planting.
- Local character is enhanced with the provision of leafy green streets.

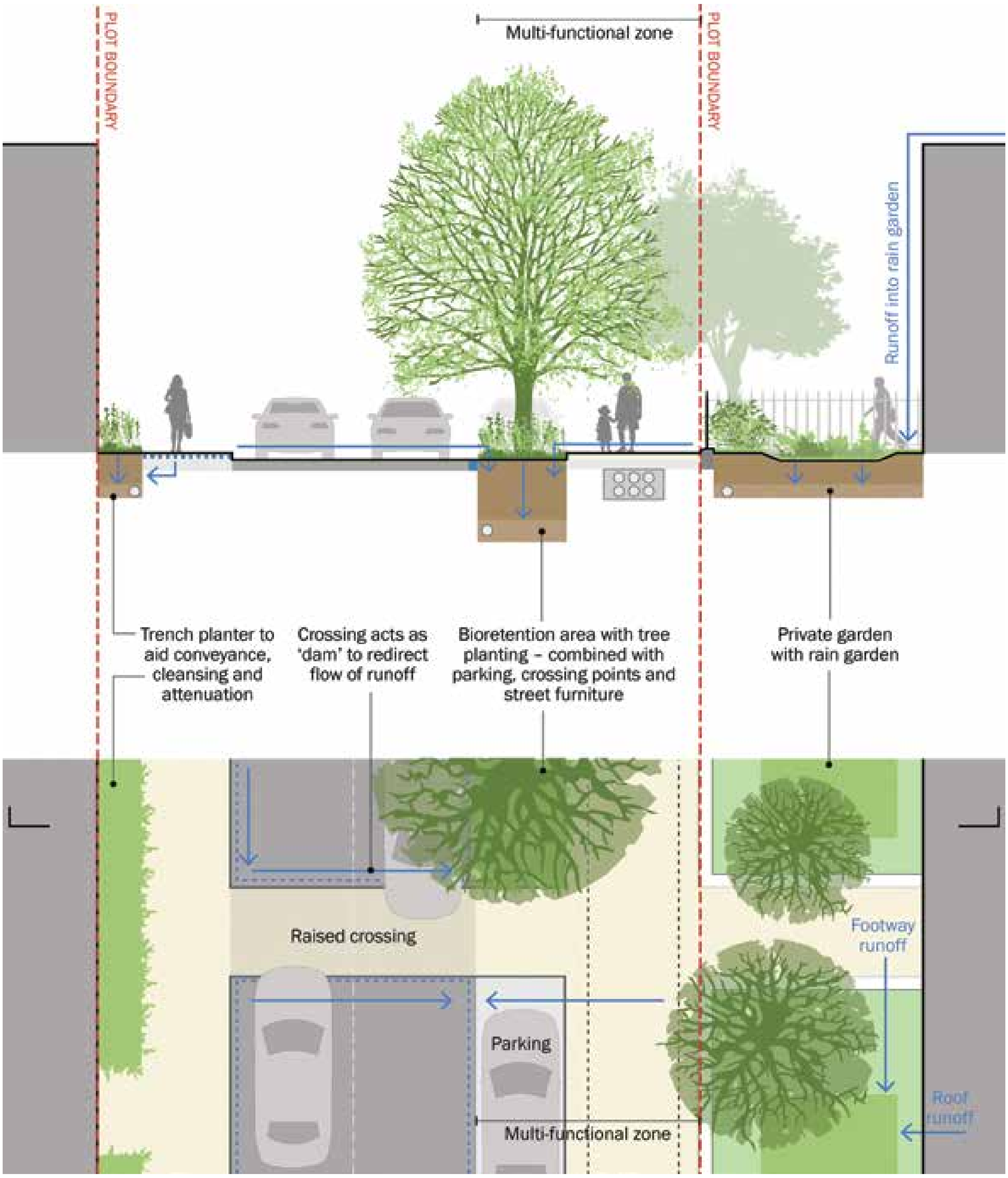


Figure 10.26 Typology 7 – Neighbourhood street

Typology 8 – Civic street

Inner city streets that have a community function and focus within a commercial setting. These streets often have changing characters, one day a retail street and the next market stalls and pop-up cafes. This typology demonstrates how SuDS can be integrated into these flexible civic spaces.

Design approach

Unlike the clearly defined plot boundaries of **Typology 7**, civic streets have blurred boundaries where highways and public realm merge with private commercial frontages that are open to the public. This imposes different pressures and priorities on the streetscape, which can be used to the advantage of SuDS. Therefore, when designing SuDS in the civic streetscape, a door-to-door approach should be adopted to ensure that the space is fully utilised.

Considerations

Civic environments need to be flexible to accommodate a variable calendar of events, an influx of people and traffic, higher levels of delivery and trash access, temporary street furniture and the desire for open frontages along retail and commercial properties. These elements should be used to define the street dimensions along with green infrastructure requirements defined by the local planning department and the functions outlined in **Typology 7**.

The parking provision and spill-out spaces associated with retail and commercial frontages provide flexible space for civic use, for example market stalls, parades and commercial launch events. There are a number of issues associated with these events in terms of visual clutter, waste/debris and vehicular congestion in the area during set-up and take-down. Therefore the event process and required infrastructure needs to be considered at an early design stage to prevent the later removal of SuDS components.

With a door-to-door approach the ownership and maintenance of SuDS needs consideration, as some SuDS components may cross boundaries.

Potential SuDS components

- The carriageway provides an exceedance event flood path.
- Combined tree trenches placed along the conveyance route provide natural irrigation for the trees and attenuate runoff rates, with outflow to the local drainage system.
- The public footpath and hard paved areas are drained using pervious pavements with sub-base storage which discharge into the bioretention systems.
- The public highway is drained with a single drainage profile into a bioretention system that incorporates tree planting. The bioretention system integrates pervious on-street parking and pedestrian crossings.
- The trench planter and the bioretention system convey water into a local detention basin if space is available or the local drainage system.
- The bioretention systems and tree pits play an important role in treating surface water runoff.

Multiple benefits

- The space is used efficiently by combining street trees, bus stops, on-street parking provision, footway, pedestrian crossing points, spaces for cycle storage, seating areas etc. SuDS can also be used to assist the traffic calming strategy through the creation of gateways that narrow the street width and, therefore, slow traffic speed.
- Biodiversity is supported by the bioretention systems and tree planting.
- Local character is enhanced with the provision of leafy green streets.

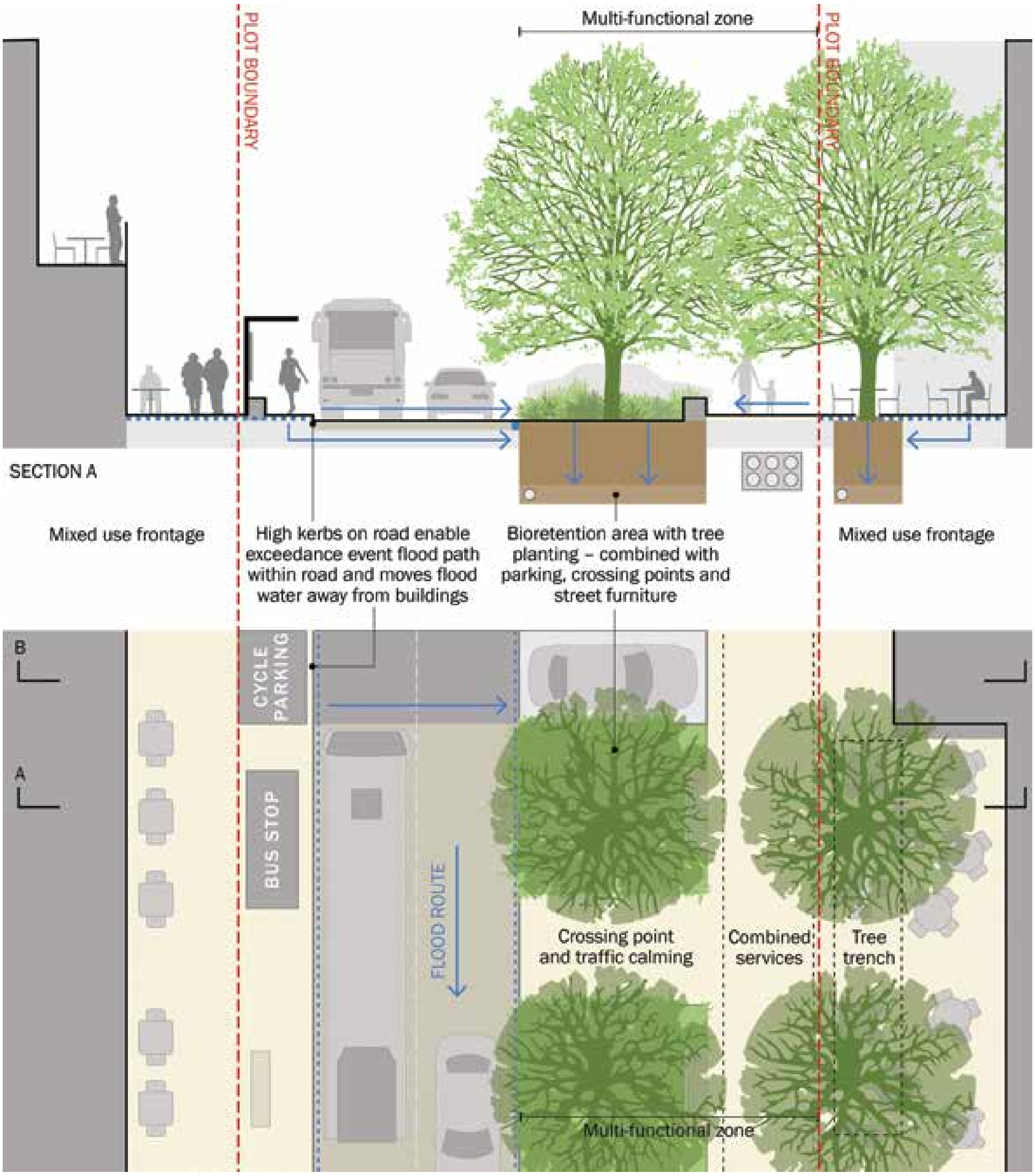


Figure 10.27 Typology 8 – Civic street

Typology 9 – Greenway

Inner city green corridors and disused historic infrastructure routes that become key pedestrian and cycle routes, connecting the city away from built-up areas, traffic and crowds. These spaces provide valuable social and biodiverse landscapes as well as connective green infrastructure, while forming an important part of the SuDS strategy for urban regeneration projects.

Design approach

Connectivity across urban landscapes supports healthy communities and promotes neighbourhood liveability. Historically, these routes are associated with canals or disused railways and historic infrastructure. Urban design master plans should consider integrating these features as purpose-made connective landscapes that also support the neighbourhood SuDS strategy.

Considerations

An important purpose of these green corridors should be to facilitate movement of people. Therefore path widths need to be suitable for all the intended users, and the predicted peak flow of people. Alongside this, the scale of strategic tree planting should also be incorporated, ensuring that the trees have enough space to mature.

SuDS components can be integrated with the tree planting but, where space allows, larger purpose-built SuDS components can also be used, such as detention basins and underdrained swales.

Directing runoff from frequent events into the greenways will provide natural irrigation for planting while treating runoff and providing a degree of natural attenuation.

Potential SuDS components

- Surface water runoff from adjacent streets and footways is directed into the greenway.
- Kerb drainage and channels keep the runoff on the surface with single drainage profiles to direct runoff into linear SuDS components.
- Incorporating landforms and deep planted troughs form flood channels, acting as detention basins during exceedance events.
- Underdrained grass areas use subsurface filter drains.
- Below-surface soakaways can be beneath planted areas or hard surfaces (only suitable for areas with adequate infiltration rates).
- A high level of strategic tree planting will increase runoff volume reduction.
- The hard surfaces surrounding the greenway are drained using pervious pavements with sub-base storage which discharge into the below-ground attenuation components.

Multiple benefits

- The greenway provides a public green space.
- The greenway connects the local community and promotes a local identity.
- Seating provision and gathering spaces enable people to interact with each other and their environment.
- The educational value can be maximised to inform users of the greenway's SuDS function, which they can witness themselves during exceedance events.
- Biodiversity is supported by the greenway planting strategy, which could include a range of flora to suit the variable planting conditions.

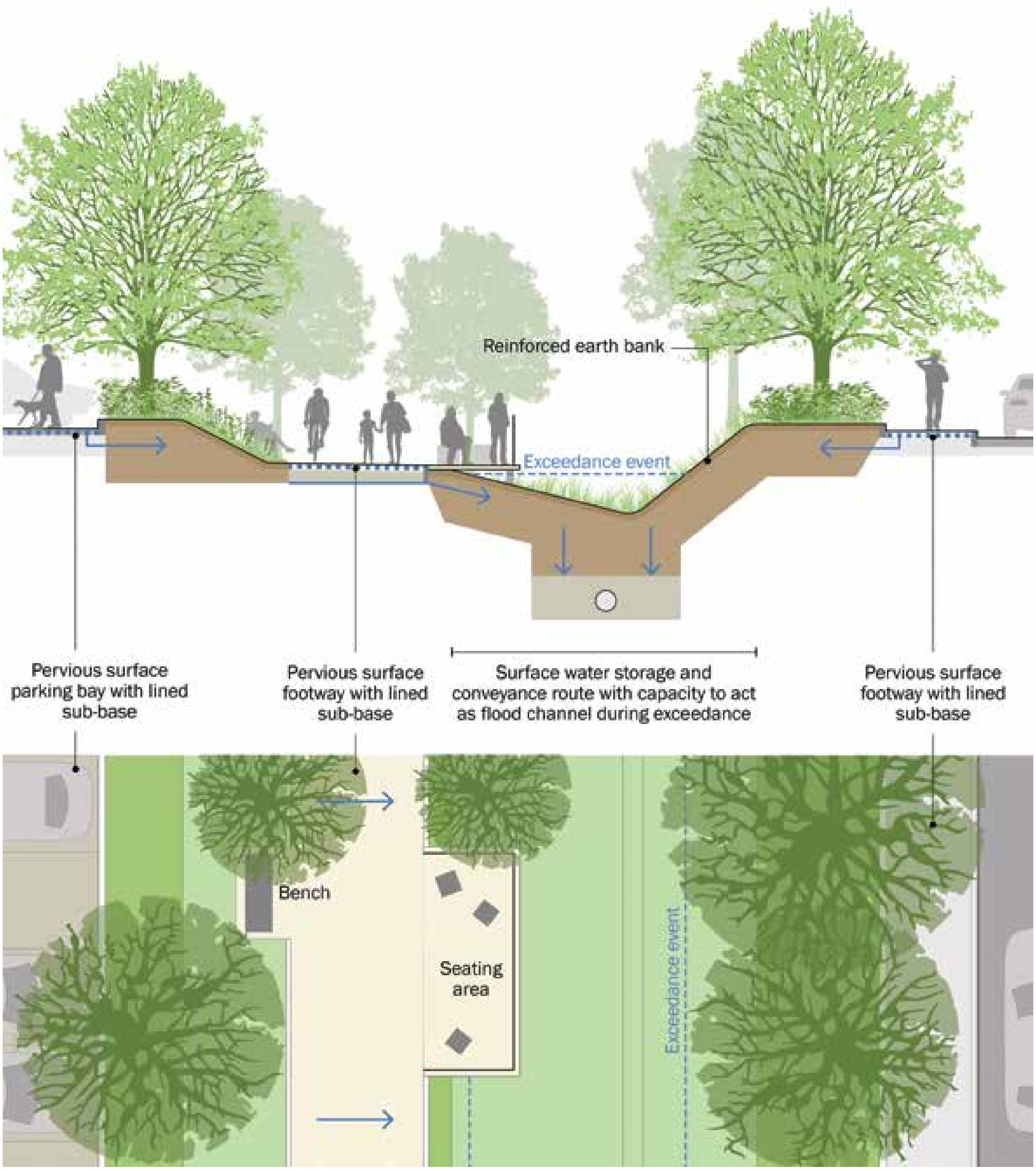


Figure 10.28 Typology 9 – Greenway

10.4 CASE STUDIES

CASE STUDY 10.2 **Bristol Harbourside**

Bristol Harbourside is a 6.6 ha mixed-use development on the edge of the city's floating harbour, which has regenerated the heart of Bristol's historic waterfront. The project creates a series of spaces and routes to enhance the floating harbour's wider public realm, including new public squares, tree-lined avenues and harbourside moorings with a new harbour inlet.

- As a brownfield site, potential pollutants from the site's former use needed to be managed.
- Runoff from roofs and pavements is conveyed through the public realm via a series of collection dishes, channels and rills.
- Runoff is used to irrigate the planted areas and enhance the character of the spaces with sound and motion.
- Along the harbour edge floating reed beds filter the runoff as it enters the harbour, providing valuable habitat opportunities and an attractive waterside setting.
- Trees and other planted areas provide Interception and infiltration.
- Green roofs and green walls are incorporated within the new buildings.

Images courtesy Grant Associates

LOCATION: Bristol, UK
DESIGNER: Grant Associates

CASE STUDY 10.3 **Derbyshire Street**

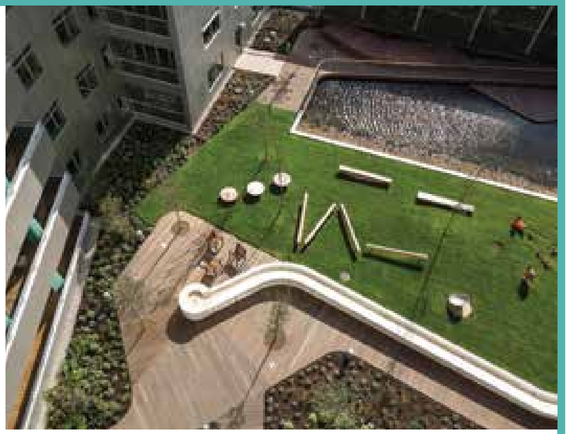
The eastern end of Derbyshire Street was a dead-end road that only served as a space for 12 parking bays, suffering from fly-tipping and providing opportunities for anti-social behaviour. The pocket park concept was developed to provide a stronger social function with a cycle lane and an outdoor café space. Core to the design philosophy was managing surface water runoff within the park and, in turn, reducing the potential for flooding locally and within the wider catchment area.

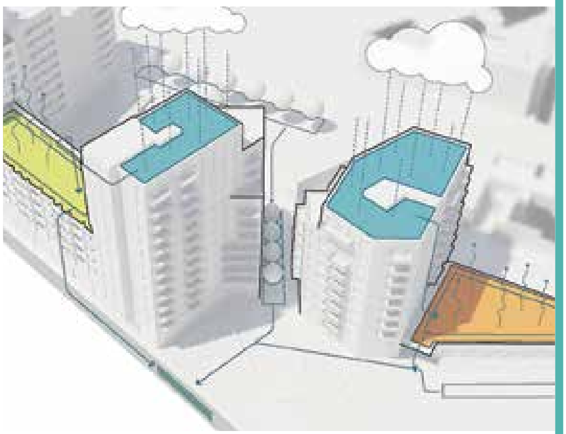
- A planted rain garden receives surface water runoff from the hard surfaces running the length of the street and provides a physical barrier between the cycle lane and the outdoor café space.
- Downpipes have been redirected into attenuating planters, providing water storage as well as overflowing into the rain garden.
- Permeable paving with infiltration into the ground is provided within the outdoor café space.
- A swale captures runoff and takes excess water from the rain garden, allowing it to soak into the ground, as well as providing a physical barrier between the cycle lane and adjacent residential flats.
- Green roofs have also been installed to provide Interception and attenuate runoff, attracting birds, butterflies and bees.

Images courtesy Greysmith Associates and London Borough of Tower Hamlets

LOCATION: London, UK
DESIGNER: London Borough of Tower Hamlets

CASE STUDY 10.4 Rathbone Market





Rathbone Market is a high-density mixed-use development in east London, including social and private housing (650 homes) and 20 000 m^2 of commercial space. It provides high-quality open space for residents as well as managing surface water runoff on site in order to limit discharge to the local drainage system.

- A pond provides a central visual feature, with plants around its margins designed to make the water relatively inaccessible. It can accommodate a 200 mm rise in water level following rainfall, providing 40 m^3 of storage.
- Treatment is provided by a filter bed beneath the planting at the edge of the pond, plus a silt trap.
- Biodiverse roofs, with planting substrate and plug plants, provide Interception and attenuation of runoff before it drains down to podium level.
- The lowest level roof is not planted, but has a series of allotment beds for use by the residents. A water butt is provided to collect rainwater from an adjacent roof for use on the allotments. The paving around the beds is also designed to collect runoff, which drains to the pond.
- A living wall absorbs noise and the water features also provide white noise to reduce the impact of the noise from the nearby main road.
- Future phases of development will include green and brown roofs with storage beneath the planting substrate using an open cellular storage system. The capacity of these roofs will be around 110 m^3.
- Connected tree pits with geotextile material for the root zone will provide further Interception and attenuation.

Images courtesy Ben Luxmoore, Tim Crocker and Churchman Landscape Architects

LOCATION: London, UK
DESIGNER: Churchman Landscape Architects

CASE STUDY 10.5 **Tanner Springs Park**

The 4200 m² pocket park in downtown Portland was opened in 2005, replacing an existing urban block. The park provides an attractive public open space with surface water detention and treatment.

- The design aims to recapture the area's wetland past with its native planting and flowing runnels, and forms one of three new parks in the Pearl District.
- Formerly a contaminated industrial site, ground conditions do not allow infiltration.
- Artwork in the park depicts the city's previous industrial landscape, adding further to the sense of place.
- The rainwater that falls within the curb-line of the park is fed into a pond with planted margins via a native grassland area and wetland, providing a natural treatment system.
- The SuDS scheme discharges to Tanner Creek, which at one time flowed openly through the site.
- During dry spells the pond water is recirculated to keep the system active.
- Community participation and a stakeholder steering group aided the delivery and legacy of the park.
- The park is maintained with the volunteer assistance of the Friends of Tanner Springs.

Images courtesy Atelier Dreiseitl and GreenWorks

LOCATION: Portland, Oregon, USA
DESIGNER: Atelier Dreiseitl and GreenWorks

CASE STUDY 10.6 **Augustenborg**

Ekostaden Augustenborg was a retrofit project aimed at making the 33 ha neighbourhood more socially, economically and environmentally sustainable.

- A phased implementation was needed around existing buildings, below-ground services, mature trees and resident communities.
- The project focused on reducing impermeable surfaces, creating green spaces and utilising above-ground SuDS including green roofs, downpipe redirection to open ditches and channels and retention ponds.
- Only limited infiltration was possible, due to clay ground conditions and the need to avoid damage to existing structures.
- Therefore, SuDS were designed primarily to attenuate surface water runoff, rather than to encourage infiltration.
- Exceedance event water features are located in public areas, including a school playground.
- There was extensive public consultation and community workshops to maximise benefits to the resident communities.

Images courtesy Illman Young

LOCATION: Malmö, Sweden
DESIGNER: VASYD

CASE STUDY 10.7 **Benthemplein Water Square**

The Water Square at Benthemplein, near the city centre of Rotterdam, is a retrofit scheme designed to manage an increasing problem of urban flooding by disconnecting urban runoff from the combined system, while also maximising the amenity value of an underused urban square.

- Three detention basins collect and store surface water runoff – two shallow basins are used during all rainfall events and the third deeper basin is only used for large events.
- Runoff is collected from the paved areas in the square and the surrounding area including roofs of the surrounding buildings.
- Runoff is conveyed via large stainless steel gutters into the basins.
- The two shallow basins allow infiltration, while the deep basin provides attenuation before discharge to a nearby canal.
- The deep basin has a hard-court sports pitch surrounded by terraced seating. The gutters and one of the shallow basins are designed to be fit for use by skaters.
- Planters have been positioned alongside areas of pedestrian movement and emphasise places where people can stop and enjoy the space.
- The planting has been selected to provide vibrant bright colours in summer and soft muted colours in winter.
- The colour scheme for the hard landscaping uses blues where water is stored and stainless steel for conveyance routes.
- The community was closely involved in the development of the design, setting the objectives of providing a dynamic place for young people, lots of space for play and meeting places, pleasant green secluded areas and the stimulating use of water.

Images courtesy pallesh+azarfane, Jeroen Musch, De Urbanisten

LOCATION: Rotterdam, the Netherlands
DESIGNER: De Urbanisten

10.5 REFERENCES

ADAPTATION SUBCOMMITTEE (2012) *Climate change – is the UK preparing for flooding and water scarcity? Adaptation SubCommittee Progress Report 2012*, The Committee on Climate Change, London, UK. Go to: **http://tinyurl.com/oa3duq7**

DIGMAN, C, ASHLEY, R, BALMFORTH, D, STOVIN, V and GLERUM, J (2012) *Retrofitting urban areas to effectively manage surface water*, C713, CIRIA, London, UK (ISBN: 987-0-86017-715-9). Go to: **www.ciria.org**

Everyone with an interest in SuDS

Those responsible for policy or decision making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

D

Audience:
Those responsible for delivering and managing a SuDS scheme

Technical detail

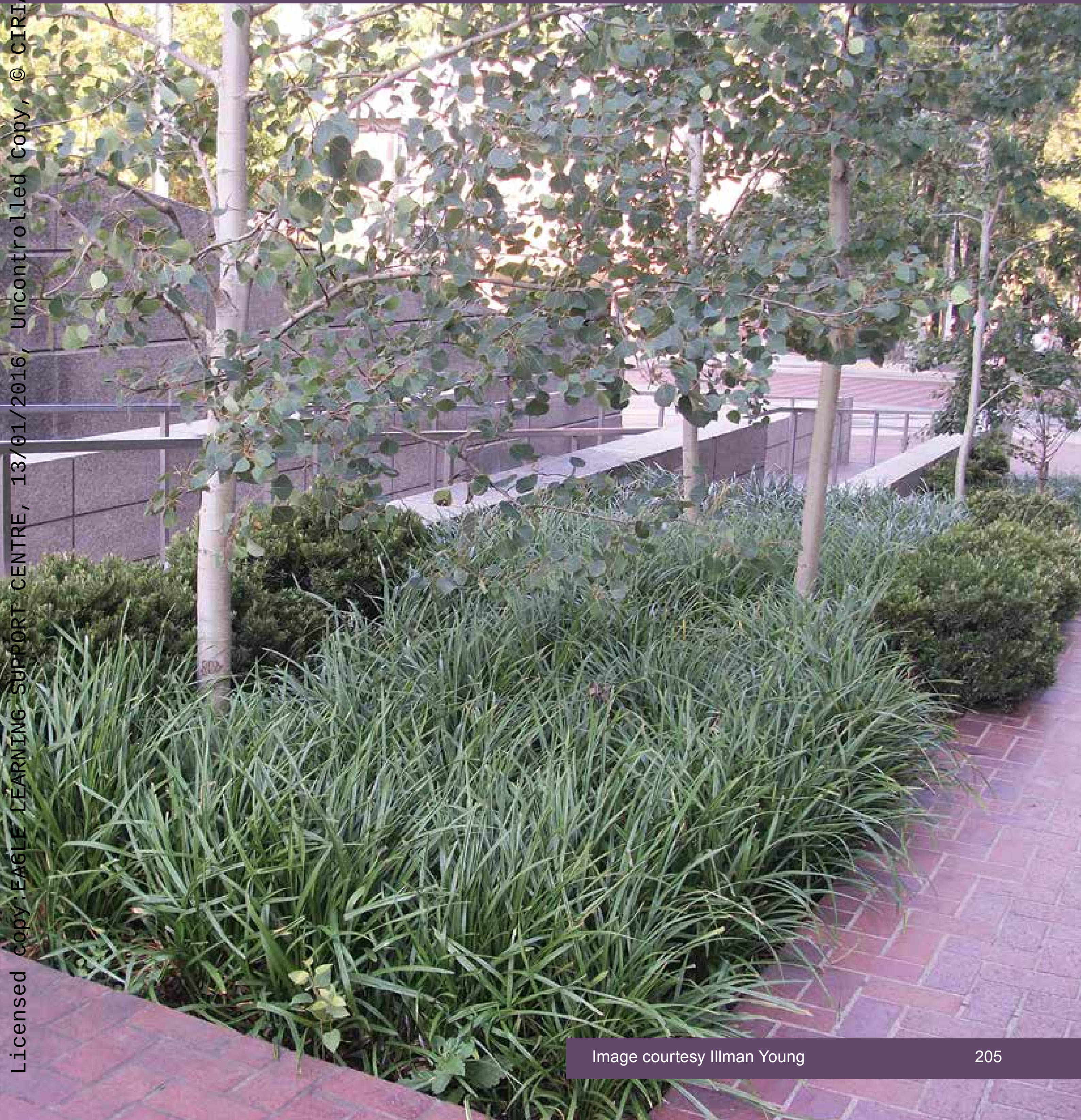


Image courtesy Illman Young

Image courtesy University of Exeter

11 RAINWATER HARVESTING

Contents

Chapter 11 Rainwater harvesting

This chapter provides guidance on the design of rainwater harvesting systems for surface water management, that is storage systems that collect runoff within the boundary of a property (from roofs and/or surrounding surfaces) for use on site, where the use is sufficiently great to ensure that storage of runoff is achievable for most rainfall events.

▶ *Appendix C, Section C.5.3 demonstrates how to design a rainwater harvesting system for a supermarket.*

11.1 GENERAL DESCRIPTION

Rainwater harvesting (RWH) is the collection of rainwater runoff for use. Runoff can be collected from roofs and other impermeable areas, stored, treated (where required) and then used as a supply of water for domestic, commercial, industrial and/or institutional properties. RWH systems have a number of key benefits:

- They can meet some of the building's water demand, delivering sustainability and climate resilience benefits.
- They can help reduce the volume of runoff from a site.
- They can help reduce the volume of attenuation storage required on the site.

Where the runoff is from trafficked areas, the potential for harvesting will depend on the proposed use of the water, the extent of pollution and the treatment provided. The collected water can generally be used for a range of non-potable purposes, such as flushing toilets, washing machines (which may require adaptation) and for external uses such as car washing and irrigation. RWH systems are rarely used to provide potable water for consumption or bathing in the UK, as this requires specialised treatment and monitoring to manage the contamination risks. In the UK, private water supplies for locations not connected to main water supply networks have to comply with the Private Water Supplies Regulations 2009.

Figure 11.1 Rainwater harvesting storage tanks for domestic and commercial application (courtesy Stormsaver)

RWH systems are designed to a specific level of service, which may address water supply only (water conservation systems) or surface water management as well (via the inclusion of further storage capacity). Provided the system is designed for supply purposes (ie it has a regular daily demand), RWHs can be considered to deliver

Interception for the contributing impermeable area and to reduce the runoff volume. This is the focus of the design methods proposed in this chapter. However, designing systems for water conservation (supply) only is also included for completeness and comparison purposes.

Much of the cost of an RWH system is related to the provision of a storage tank, the pump and the power, controls and the pipework required for its operation. The cost of providing an additional 1 to 3 m^3 of storage will therefore usually lead to a relatively small increase in the total system cost. For a property with a roof of 50 m^2 the additional storage needed to capture a 60 mm (total depth) rainfall event would commonly be around 3 m^3.

The principal documents that provide guidance on the design of RWH systems are as follows:

- BS 8515:2009+A1:2013 *Rainwater harvesting systems. Code of practice*
- BS 8542:2011 *Calculating domestic water consumption in non-domestic buildings. Code of practice*
- BS 8595:2013 *Code of practice for the selection of water reuse systems*
- EA (2010) *Harvesting rainwater for domestic uses: an information guide*.

Although water butts are often regarded as a form of RWH, in practice their value is limited to domestic watering during dry periods when there is garden water in the container. Water butts do not guarantee that storage will always be available, unless the system is designed so that any water stored above a set threshold drains slowly to the downstream drainage system or to a soakaway. However, there is no robust evidence regarding the potential effectiveness of such components during significant events and no guidance on the size of orifice and storage volume that may be required to ensure suitable performance levels. Modelling would, therefore, be required.

Table 11.1 summarises the different possible objectives for RWH systems and the implications for their design.

There are three main types of RWH system:

- gravity-based systems
- pumped systems
- composite systems

These are described in the following sections. In all cases there is a need to ensure that, if the store of non-potable water is depleted, an appropriate alternative supply of water is available for the relevant appliances.

TABLE 11.1 RWH objectives and design implications

RWH for water conservation (supply) only
The RWH system is designed to supply water to the building that it serves. The storage provided is sized to capture and retain an appropriate volume of runoff from the contributing surface (the yield) to meet the projected building use requirements (the demand). Although a proportion of the runoff from large events will normally be captured, the performance of such systems to manage extreme events cannot be relied upon, and therefore any potential contribution to surface water management should not be allowed as part of the design.
RWH for water conservation (supply) and surface water management, passive systems
The tanks for these systems are sized to accommodate the storage required for water supply plus the storage required to manage a specific depth of rainfall during a large event. The term "passive" refers to the fact that the space available in the tank to store surface water runoff at any particular time is entirely dependent on the balance between the demand and supply, and the water level is not "managed" in an "active" way. Where RWH systems are implemented for individual residential properties, surface water control for the design rainfall event is unlikely to be achieved for every property, and an average level of compliance will need to be assumed. Where groups of properties share a tank, or where consistent demand in commercial buildings is more likely, performance of the system is more certain.
RWH for water conservation (supply) and surface water management, active systems
If the water storage in a tank is actively managed, then all properties can be designed to comply with surface water management objectives, irrespective of the relative levels of demand and supply, provided the system is managed so that no runoff (of any significance) occurs for any event up to the design rainfall depth. There are two mechanisms available to ensure that sufficient tank volume is available to manage the design storm depth. These are: ▪ forecasting that a large event is approaching (days or hours ahead) and pumping the stored water away, or ▪ pumping out the stored water down to a set level whenever a threshold is exceeded. The first option requires communication to rainfall event forecasting information. The second requires a timer delay so that water is pumped away at a set time after the event has passed.

BOX 11.1 Rainwater harvesting for schools, Essex

At Columbus School and College in Chelmsford, rainwater is harvested from both sites in a combined storage and treatment facility. The water is then distributed for use in the toilets.

RWH forms part of a wider water management strategy, which also includes SuDS to manage local flooding, water-efficient fittings and fixtures plus leak detection systems and drought resistant planting.

The scheme forms part of a wider strategy by Essex County Council to improve sustainability standards and reduce costs.

Figure 11.2 Columbus School and College (courtesy Essex County Council)

Several other schools in the county also use RWH. Monitoring of different systems is helping to inform future schemes.

11.1.1 Gravity systems

Gravity systems are designed so that the rainwater is collected by gravity and stored at elevation so that it can also be supplied by gravity (**Figure 11.3**).

Rainfall runoff can be collected from standard domestic or commercial property pitched roofs and stored in the roof space or on the roof. In other designs, the storage is supported at a high level on the wall just below gutter level. In low elevation buildings, above-ground storage tanks can be used to serve ground floor appliances and irrigation demands.

The key design constraints are:

- the structural capacity of the building to store the water at an elevated location
- the collection of sufficient water from the roof, at sufficient height, that will allow subsequent supply based on a gravity-only process
- limiting operating pressure
- temperature of stored water.

Modern domestic properties are generally quite lightweight structures and only designed to meet standard loadings, which includes the storage of cold water tanks in lofts. The roof area of a standard pitched roof tends to fall to a level equal to or below the loft space, therefore collecting water by gravity and storing it in the loft has to limit the collection area to the upper section of the roof unless below-gutter storage options are used (where they can be supported structurally).

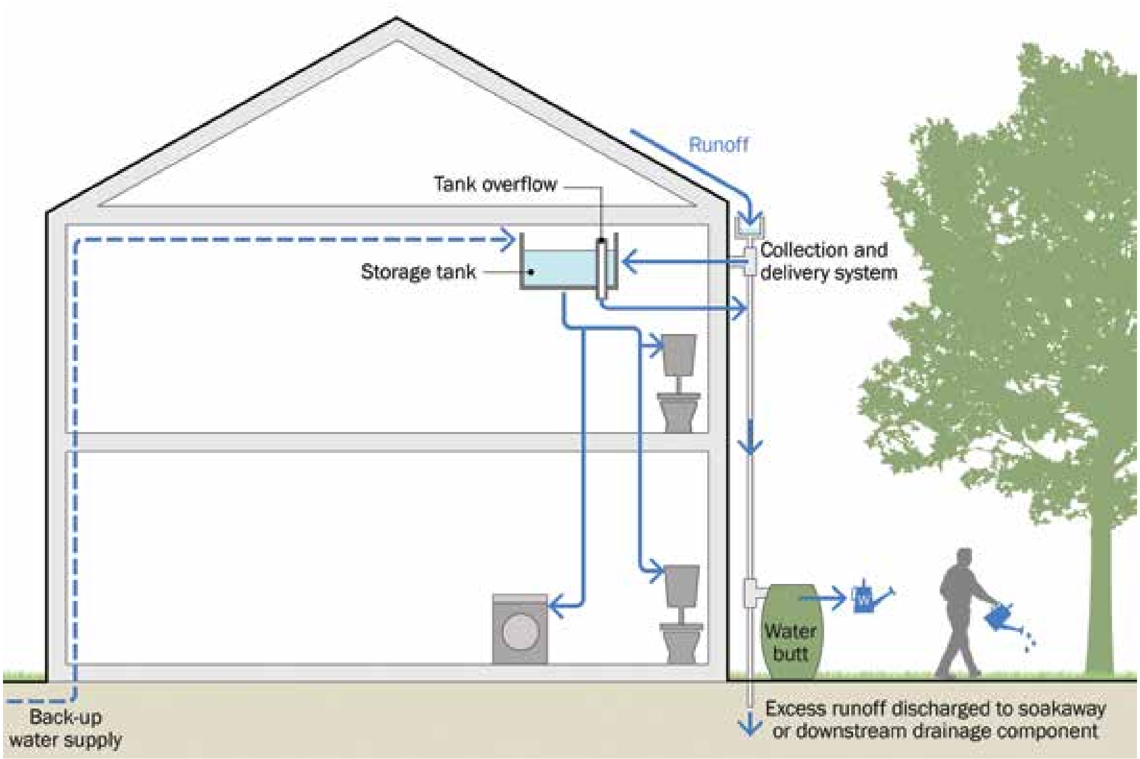


Figure 11.3 A conceptual gravity-fed RWH system

11.1.2 Pumped systems

The most common type of RWH systems tend to store water underground or at ground level and then pump it out for supply purposes.

There are two types of pumped systems: those that pump to a header tank and those that pump directly to the units in the buildings.

A typical pumped RWH system is shown in **Figure 11.4**.

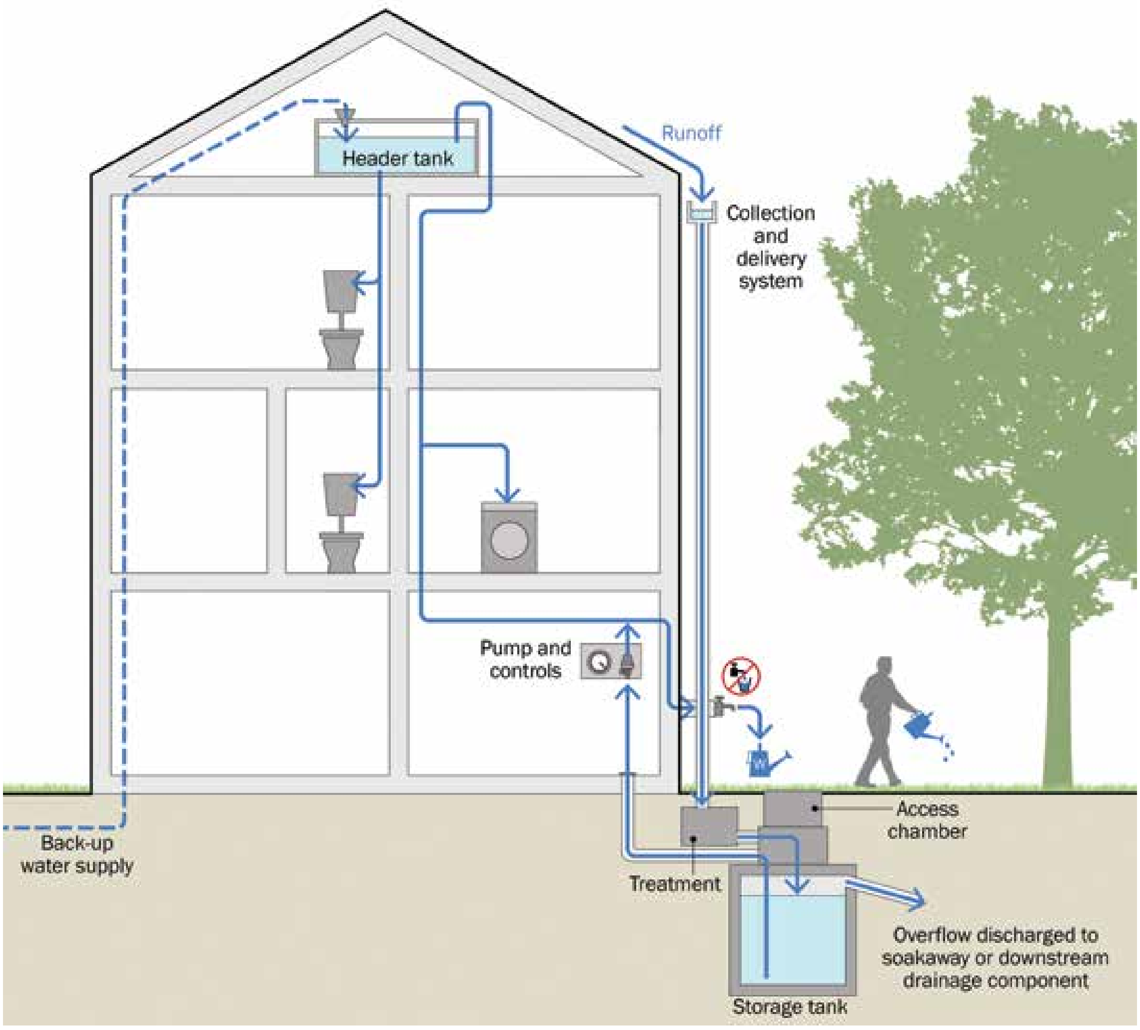


Figure 11.4 A conceptual pumped rainwater harvesting system

11.1.3 Composite systems

These systems use the advantages of both gravity and pumped processes. Runoff collected by gravity is passed directly to a large header tank, while excess runoff (and runoff from areas that cannot drain by gravity to the header tank) can be stored in the main tank in the ground. If and when the header tank is empty, a pump then comes into operation to fill it from the main storage tank. Although the header tank is likely to be much smaller than the main tank, the amount of water which needs to be pumped is often very significantly reduced compared to a fully pumped system.

11.2 SELECTION AND SITING OF RWH SYSTEMS

Rainwater harvesting can be used in residential, commercial or industrial development for new or retrofit projects for water conservation and surface water management. Careful consideration should be given to the likely contaminants present in the runoff, and thus the suitability of the runoff for harvesting; for example, runoff from roofing materials containing copper or zinc, or treated with fungicides or herbicides, may not be suitable, depending on the purpose for which the water is to be used.

There are a number of site-specific features that will influence how RWH systems are designed (in addition to the considerations of contributing area, property demand and elevation discussed in **Section 11.1**).

Selection and siting of RWH systems will depend on the size and access requirements of the tank and the physical constraints of the site. In all cases, easy but safe access is needed to all components (filters, pumps etc) to ensure that there is no impediment to maintenance being carried out.

Storage tanks should be placed in a safe, secure location either underground, indoors, on roofs or adjacent to buildings (depending on the intended uses of the water). Tanks that are located underground tend to have improved performance with respect to the control of water temperature, reducing bacterial growth in summer and frost damage in winter. Where the tank has to be installed close to the building, structural considerations such as the depth of the foundations and the watertightness of the RWH unit and its overflow provision are particularly important. The presence of underground utilities may also constrain the location of the tank.

Tanks should not generally be placed on filled ground, and an adequate geotechnical investigation should be undertaken to ensure the suitability of the soils for the tank foundation.

The storage tank is quite likely to be empty for periods of time and, where groundwater levels are close to the ground surface, the issue of flotation will need to be addressed.

11.3 HYDRAULIC DESIGN

11.3.1 General

The sizing of an RWH storage tank is a function of:

- the demand for non-potable water from the tank
- the regularity of the demand
- the area contributing runoff to the tank
- the local seasonal rainfall characteristics
- the design level of service for the tank, with respect to the control of surface water.

An accurate assessment of the performance of an RWH system requires the pattern of demand to be modelled, together with a continuous rainfall time series and runoff model. This enables temporal patterns of supply, storage and demand to be predicted, together with frequencies of overflow operation and supply shortfall. However, in most instances, this approach is not needed and a simplified calculation of tank storage can be used.

The RWH code of practice BS 8515:2009+A1:2013 provides six ways of calculating tank sizes. These are:

1. the simple method – for water conservation
2. the intermediate method – for water conservation
3. the simple surface water management method – with passive control
4. the intermediate surface water management method – with passive control
5. the detailed surface water management method – with passive control
6. the surface water management method – with active control.

Each of these methods are discussed in the following sections. It should be noted that the surface water management options automatically provide an equivalent (or better) level of service with respect to water conservation (supply). An automated calculation of storage tank size for residential RWHs can be accessed from **www.uksuds.com**

In all cases, there is an assumption that regular daily demand will take place. If there are unusual demand requirements, then analysis from first principles will be needed. This applies to all uses of RWH systems – whether residential, commercial, industrial or institutional.

The primary parameters used for calculating the size of the storage are:

- the storm rainfall depth that is to be captured
- average annual rainfall (AAR)
- daily demand for non-potable water
- building occupancy
- contributing surface area.

These are described in the following subsections. Other parameters include the runoff factor and the filter efficiency factor.

Design level of service for the tank (design rainfall depth)

The design rainfall depth can be any value. However, site runoff volumetric control criteria are often linked to the 1 in 100 year, 6-hour event, which tends to be of the order of 60 mm in the UK (**Figure 11.5**).

Average annual rainfall for the UK

The average annual rainfall across the UK can be obtained by reference to tools such as the *Flood Estimation Handbook* (FEH) CEH, 1999) or the mapping from the older *Flood Studies Report* (FSR) (IOH, 1975). **Figure 11.6** provides an indication of the annual rainfall depths across the UK.

Daily demand for non-potable water

The assumed consumption of non-potable water has historically been 50 litre/capita/day (l/c/d) for toilet flushing (assuming 9 litre cisterns). However, with recent developments in water-efficient appliance design (eg maximum toilet cistern size of 6 litres), daily household toilet usage is now thought to be closer to 20 l/c/d (Kellagher, 2012). The consumption of water in washing machines is believed to be of the same order at around 20 l/c/d. This means that 40 l/c/d could be assumed if both appliances use non-potable water. These figures have been based on research (Kellagher, 2012), but there is some degree of uncertainty over whether these figures are suitable averages to use, and as variations in water use are likely to be significant between households, it is important to assume a conservative (low) value when designing for surface water runoff management.

For commercial properties such as offices where toilet flushing alone is used during the working day, the consumption rate may be as low as 10 l/c/d. Guidance on water consumption for any category of building should be obtained when designing for non-potable water use (BS 8542:2011). For other buildings where water demand is driven by temporary customer use (eg schools, large stores, supermarkets) consumption needs to be based on specific information associated with the buildings being served.

Occupancy rates of domestic properties

The occupancy rates of properties are available from statistical information gathered by the government and regional authorities. These are linked to type of property which includes the number of bedrooms. The average occupancy values are supported with information on standard deviation, which is important when assessing the degree of compliance of individual property RWH systems in managing runoff from a specific design storm depth.

An illustration of values for household occupancy is provided in **Table 11.2** and these are fairly representative of many other regions of the UK.

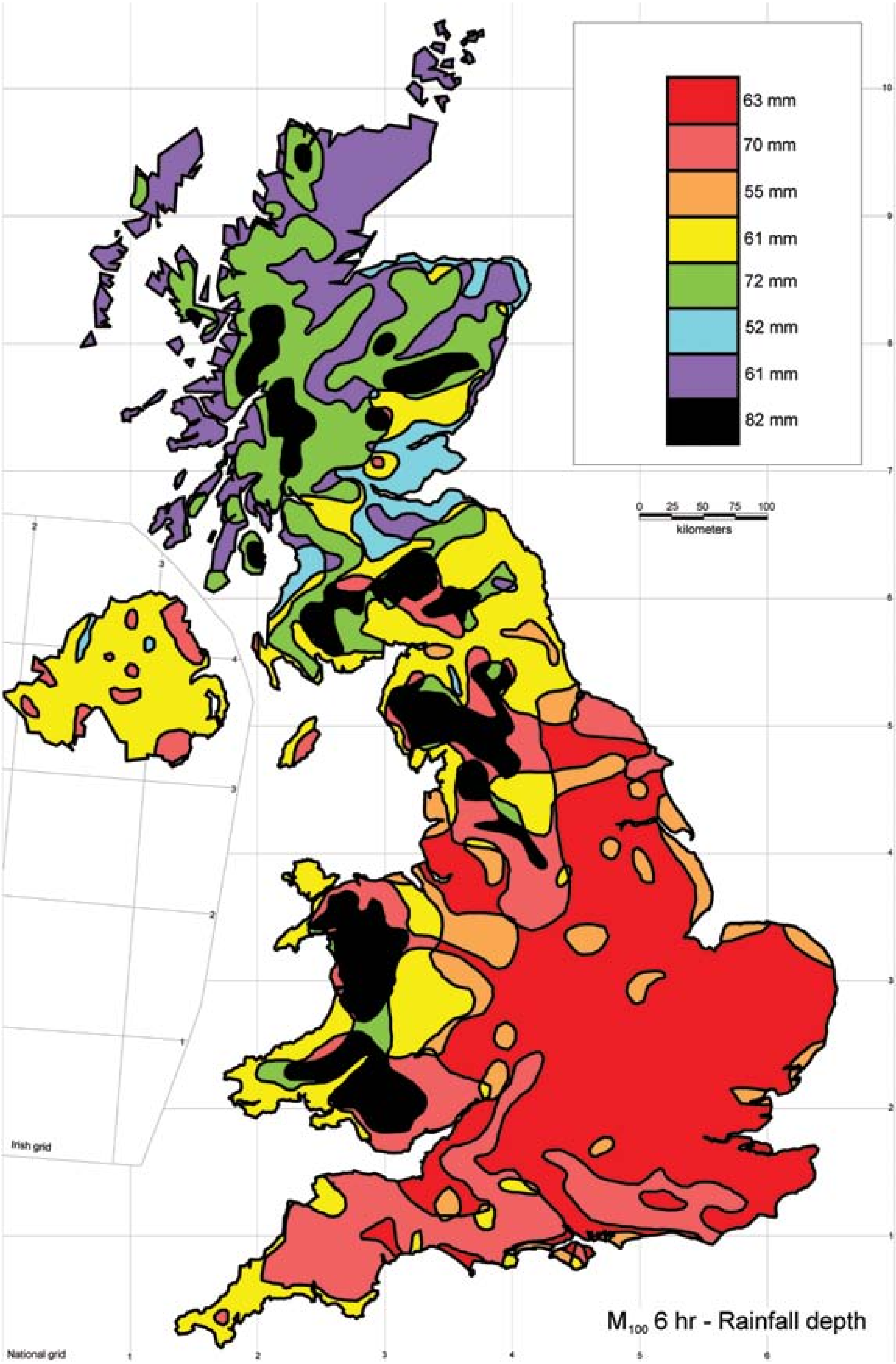


Figure 11.5 1 in 100 year, 6-hour rainfall depths for the UK

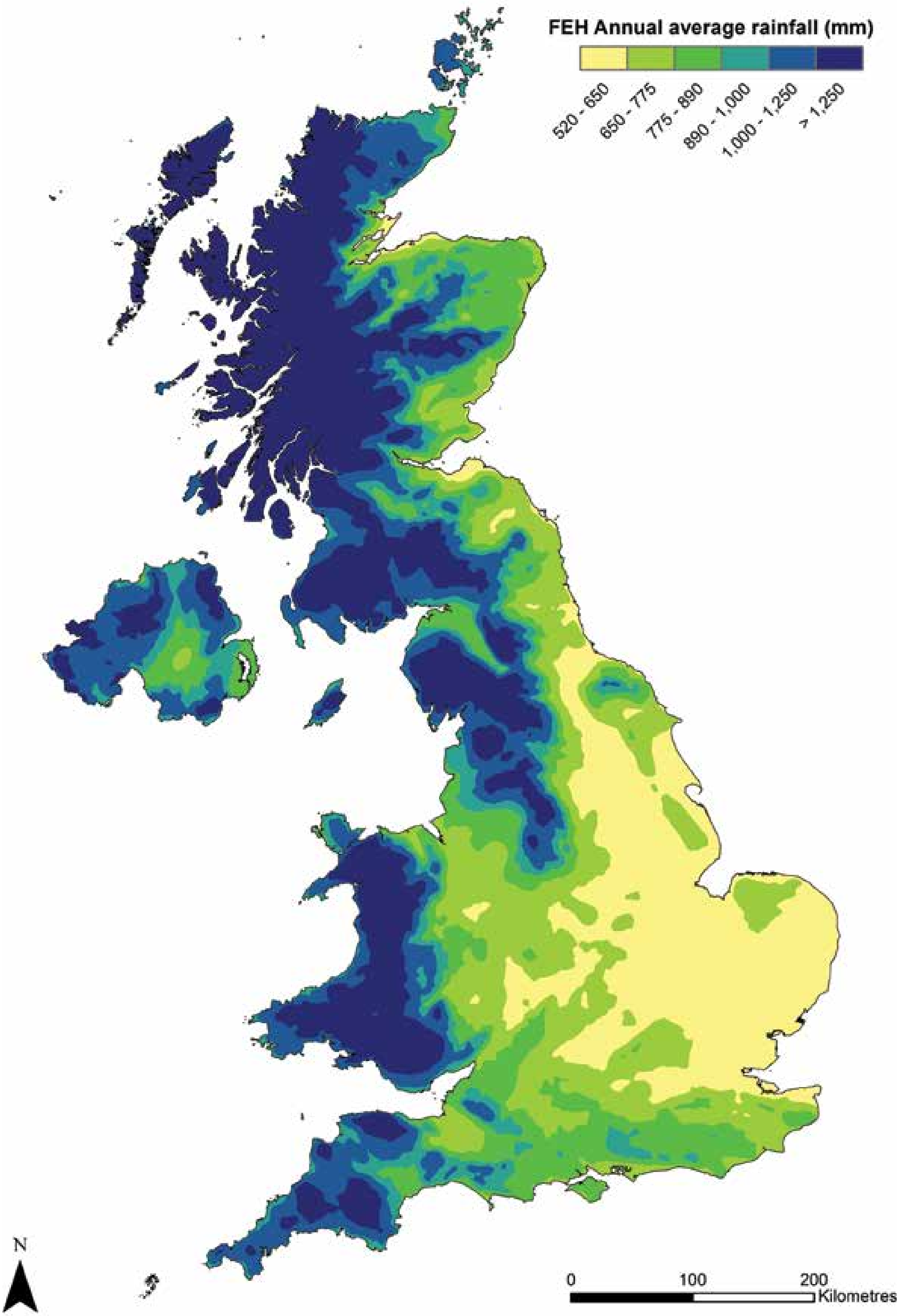


Figure 11.6 Average annual rainfall for the UK

TABLE 11.2 **Summary of occupancy rates for new market housing in (i) Cherwell District and (ii) Oxfordshire County (from OCC, 2009)**

	Number of bedrooms in the property						
	0	1	2	3	4	≥5	Overall
(i) Cherwell District							
Properties sample size	3	84	210	243	145	87	772
Number of occupants	3	118	362	579	431	295	1788
Mean occupancy	1.00	1.40	1.72	2.38	2.97	3.39	2.32
Standard deviation	0.00	0.58	0.66	0.97	1.12	1.24	0.92
(ii) Oxfordshire							
Properties sample size	28	514	1191	1044	809	311	3897
Number of occupants	31	716	2069	2453	2443	1138	8850
Mean occupancy	1.11	1.39	1.74	2.35	3.02	3.66	2.27
Standard deviation	0.42	0.56	0.73	1.02	1.17	1.32	0.95

Table 11.3 provides suggested typical occupancy rates for England, for all dwellings that are not assisted housing or in locations with unusual occupancy characteristics for economic or cultural reasons. Updated and equivalent data for England, Wales and Scotland is collected as part of the national census, and is available for each region: **www.scotlandscensus.gov.uk/census-results / https://www.nomisweb.co.uk/census/2011**

TABLE 11.3 **Occupancy by accommodation type and number of bedrooms, England 2004–2007 (from DCLG, 2007)**

Type of accommodation and number of bedrooms	Mean household size
One bedroom	1.3
Two bedrooms	1.9
Three bedrooms	2.6
Four or more bedrooms	3.2

For water conservation design, a traditional rule of thumb is two persons per bedroom, although the figures in **Table 11.3** indicate that this may be conservative, and perhaps the mean occupancy plus one standard deviation (if this is known) is a more reasonable estimate to use.

For surface water management design, the mean occupancy should be used, which is conservative for this aspect of the design.

Contributing plan areas

Contributing roof areas should be calculated in plan. It is important to use the actual roof plan area drained as it may not be possible to capture all the runoff from a roof area due to the various pitch arrangements of the property.

Runoff (yield) coefficients

It is important to recognise that many events are relatively small and therefore the initial wetting losses, especially for flat roofed areas, may be quite significant which can mean that the overall proportion of runoff for an event is much less than 100%. Where losses are complex and varied, such as on green roofs and permeable pavements, then analysis with a continuous rainfall time series, taking into account evapotranspiration may be necessary to get a sufficiently accurate estimate of the likely proportion of runoff. **Table 11.4** provides suggested values for the average runoff coefficient.

TABLE 11.4 **Suggested initial runoff coefficients for RWH yield analysis (from BS 8515:2009+A1:2013)**

Surface type	Runoff coefficient
Pitched roof with profiled metal sheeting	0.95
Pitched roof with tiles	0.90
Flat roof without gravel	0.80
Flat roof with gravel	0.60
Green roof, intensive[1]	0.30
Green roof, extensive[1]	0.60
Permeable pavement (concrete blocks)[2]	0.60
Road/pavement	0.75

Note

1 Green roof runoff yield is particularly uncertain and varies with season. There may also be negative colouration impacts.

2 This reflects the proportion of rainfall that finds its way through the overlying surface to subsurface collection points for RWH.

The runoff coefficients suggested for green roofs and permeable pavements in particular are likely to be higher than would be observed for most small-to-medium events (ie they will give too high an estimate of yield and associated yield/demand ratio).

An alternative approach to the calculation of the runoff yield can be used which explicitly addresses both the losses for each event and the runoff coefficient losses once the collection surface is wet. **Table 11.5** provides indicative values for various roof surfaces for this approach.

TABLE 11.5 **Runoff coefficients with initial losses for RWH yield analysis (from BS 8515:2009+A1:2013)**

Surface type	Surface type runoff coefficient	Depression storage loss (mm)
Pitched roof with profiled metal sheeting	1.0	0.2
Pitched roof with tiles	1.0	0.4
Flat roof without gravel	0.95	1.0
Flat roof with gravel	0.95	2.0
Green roof, intensive[1]	0.80	2.0–6.0
Green roof, extensive[1]	0.80	2.0–4.0
Permeable pavement (concrete blocks)	0.90	4.0
Road/pavement	0.90	1.5

Note

1 Green roof runoff yield is particularly uncertain and varies with season. There may also be negative colouration impacts. Intensive and extensive green roofs are described in **Chapter 12**.

For small roofs, it is unlikely that green roofing would be used together with RWH as the natural losses from green roofs are large and demand would be significantly greater than the available supply. However, for very large roofs (or where demand is limited) there may be a need to use both in conjunction in order to adequately meet surface water volume control requirements.

Hydraulic filter efficiency

Runoff losses are increased by filter losses. Filters vary in the way they work, and these losses are also a function of the rainfall depths and intensities. It is best to use an appropriate coefficient for the actual filter used in the design (obtained from the manufacturer), but a coefficient of 90% can be adopted as a starting point.

11.3.2 Sizing RWH storage tanks for water conservation (supply) only (BS 8515:2009)

The sizing of storage tanks for water conservation (supply) systems is generally based on a value that is the smaller of either 5% of the annual property water demand or 5% of the annual runoff "yield" of the contributing surface. The approach remains the same for one or more than one property and assumes:

- reliable regular daily demand for the water, and
- fairly similar monthly rainfall depths throughout the year.

The 5% figure is based on the presumption that 5% of the year (ie 18 days) provides enough time for the rainfall yield to approximate to the average yield.

Where the RWH system does not have a regular demand, and/or where a large amount of water might be needed infrequently (eg a garden centre), then the design will need to take account of the seasonality of both supply and demand patterns.

The simple method

The simple method is just a graphical representation of the formula-based intermediate method (see below). This allows the capacity of the storage tank to be determined based on an assumed number of occupants (in this case, four people), the annual rainfall depth and the size of the roof of the property (plan area). **Figure 11.7** illustrates the approach, drawn from BS 8515:2009+A1:2013. A roof runoff coefficient of 80%, a water demand per person of 50 l/c/d and 18 days of storage have been assumed in producing the figure.

To avoid having a separate figure for different occupancy rates, the information can be aggregated to one figure, as illustrated in **Figure 11.8**. The horizontal lines for each property occupancy defines the maximum storage that is appropriate for that property, due to the limit in the demand.

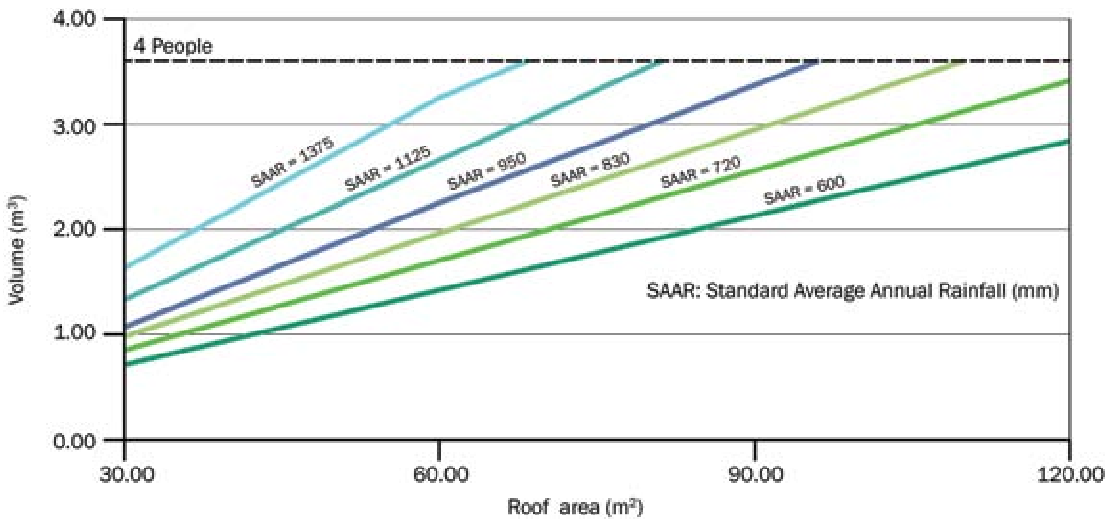


Figure 11.7 The simple method for sizing RWH tanks – for water conservation only (from BS 8515:2009+A1:2013)

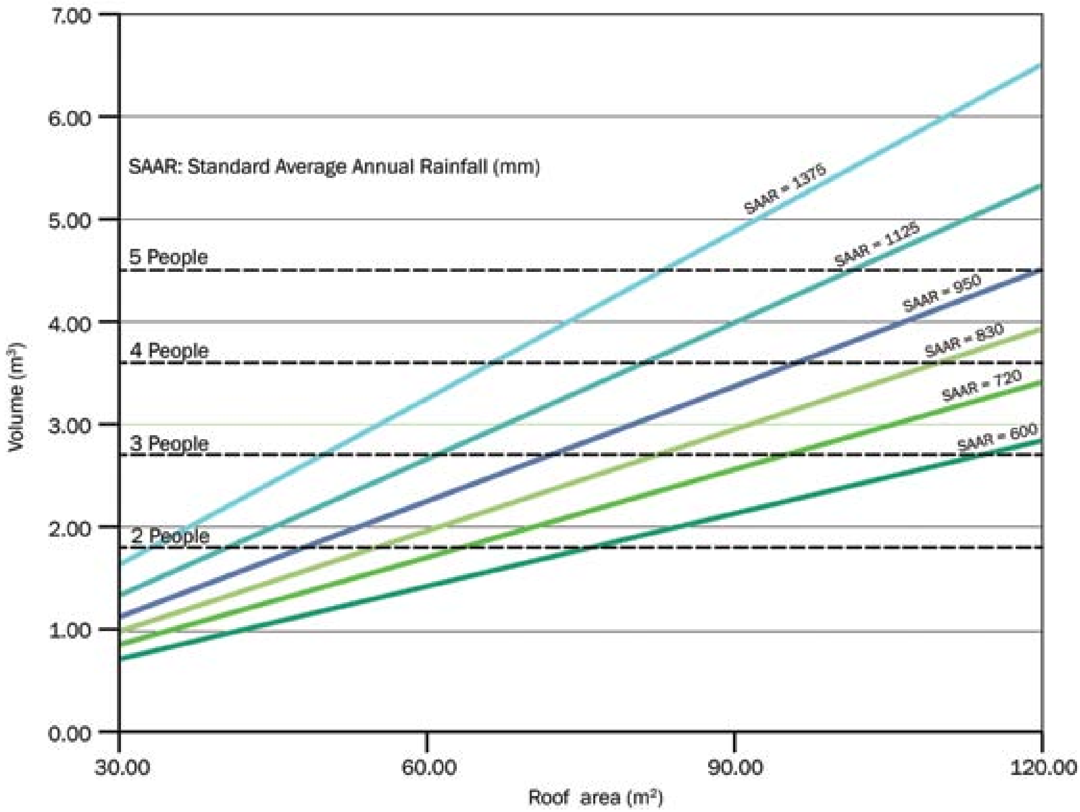


Figure 11.8 The simple look-up approach for sizing RWH tanks – aggregated for various occupancy rates

The intermediate method

The intermediate method is based on calculating the lesser of "5% of the annual runoff yield" and "5% of the annual property demand" as set out in the following sections. The 5% represents approximately 18 days of supply/demand and is required to ensure that sufficient storage is available, being suitably conservative so as to take account of the variability in rainfall/demand patterns.

BOX 11.2 Runoff yield calculation (intermediate method: water supply only)

Five per cent of the average annual runoff from the contributing area is calculated using the following equation:

$$Y_R = A\ e\ AAR\ \eta \times 0.05$$

where:

Y_R	=	runoff volume (yield) (l)
A	=	collecting runoff area (m²)
e	=	runoff (yield) coefficient
AAR	=	average annual rainfall depth (mm) (**Figure 11.4**)
η	=	hydraulic filter efficiency (ratio)

An alternative formula, which takes into account the number of events in the year and the initial losses, is:

$$Y_R = [AAR - (150\ ds)]\ e_2\ \eta\ A \times 0.05$$

where:

d_s	=	depression storage mm)
e_2	=	runoff (yield) coefficient (after depression storage has been filled)

This formula assumes that there are 150 effective rainfall events in the year, which is a reasonable assumption for most of the UK.

BOX 11.3 Non-potable water demand calculation (intermediate method: water supply only)

Five per cent of the annual non-potable water demand is calculated using the following equation:

$$D_N = P_d\, n \times 365 \times 0.05$$

where:

D_N	=	total annual property demand for non-potable water (l)
P_d	=	daily demand per person (l)
n	=	number of occupants in the property

11.3.3 Sizing RWH storage tanks for surface water management, with passive control

All surface water management methods are based on two criteria:

1. A design rainfall depth is to be captured by the system without the overflow coming into operation.
2. The average annual demand (D_N) is greater than the average annual yield (Y_R) from the contributing area.

Where seasonal variability is significant, data should be used for the season for which large rainfall event control is relevant.

The demand assessment is based on assumed occupancy and water usage. As a result of the "passive" control approach and the variability in property occupancy (and therefore consumption), surface water control for the design event is unlikely to be achieved for every property. Where demand is lower than average, the RWH tank will tend to have lower availability for the storage of runoff. A rule of thumb should therefore be adopted that assumes that 30% of properties on any site will "fail" to control surface water runoff for the design event.

The water demand for a group of properties sharing a communal RWH tank is more predictable as the total population for a group of houses will tend to converge toward the average. Therefore the more properties there are sharing a tank, the less likely the tank is to fail to deliver surface water management for the design rainfall depth. Demand predictability is also likely to be higher for commercial properties.

There are design uncertainties regarding how many houses are needed to achieve sufficient convergence on the mean water consumption, and what the chance of "failure" is for the system with respect to managing the design event. These questions can be addressed using appropriate statistical analysis. However, as the consequences of failure of a communal system is greater (if it is being presumed that the runoff volume is being stored), a degree of conservatism needs to be exercised in the analysis of assessing the yield and demand ratio. As the number of properties served by a communal rainwater system increases, the uncertainty associated with the demand level reduces and the likelihood that Y_R/D_N is greater than 0.9 is lowered.

The simple method

For the simple method, the Y_R/D_N ratio should be less than 0.7. This method calculates the water conservation (supply) component and the surface water management storage volumes separately and simply adds them together. However, for the situation where the demand (D_N) is more than three times the yield (Y_R) (ie where $Y_R/D_N < 0.33$), the total storage that needs to be provided can be limited to the storage required for surface water management alone.

The storage calculation is set out in **Box 11.4**.

BOX 11.4 Tank storage volume calculation: simple method, water conservation + surface water management, passive control

When:

$$D_N - 3.0\, Y_R < 0$$

Then:

Total storage = V_{SC}

Where:

$$V_{SC} = \frac{A\, R_d\, \beta\, \eta}{1000}$$

V_{SC}	=	storage volume (m^3)
A	=	contributing runoff area (m^2)
R_d	=	design storm event rainfall depth (mm)
β	=	design storm event runoff coefficient
η	=	hydraulic filter efficiency (ratio)

When:

$$Y_R / D_N < 0.7$$

Where:

Y_R	=	5% of the annual volume (yield) (l) (**Box 11.2**)
D_N	=	5% of the annual demand (l) (**Box 11.3**)

Then:

Total storage = $V_{SC} + Y_R$

It is important to note that the design storm event runoff coefficient should be 90% or more from most surfaces which is different from the coefficient used for the calculation of Y_R. In contrast the coefficient η might be slightly less, in that the event is likely to be a higher intensity event, but this will be product-specific.

Figure 11.9 provides a look-up graph for V_{SC}. It assumes that both the runoff factor and filter efficiency are 1.0 (ie no losses) and that the design rainfall event depth is 60 mm.

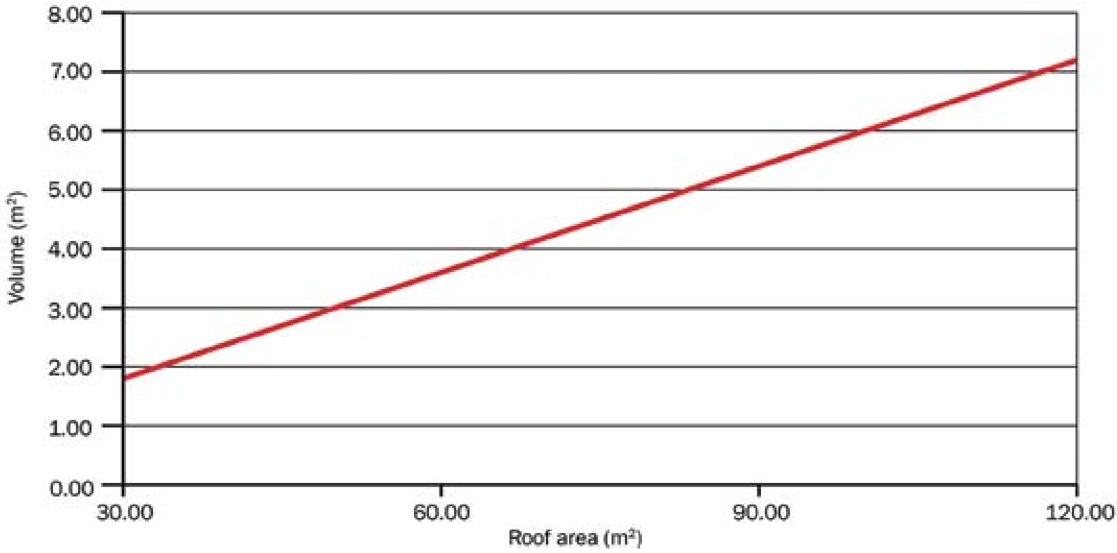


Figure 11.9 Additional storage volume V_{SC} required for surface water management, over and above the storage needed for water conservation, simple approach

The intermediate method

The intermediate method is effectively a minor refinement of the simple method. The extra assumption is that, where Y_R/D_N ranges between 0.33 and 0.7, the storage provision for water conservation can be reduced to minimise the increase in volume needed for surface water management. In all other aspects the constraints and design criteria are the same as those given for the simple method for surface water management.

The detailed method

This method can be used for all scenarios where $Y_R/D_N < 0.9$. In this scenario, storage volumes calculated using the simple or intermediate methods will underestimate the storage requirements.

This methodology is based on the research work of Gerolin and Kellagher undertaken to avoid the need to carry out extensive analysis using a continuous rainfall time series (Kellagher, 2012). This method does not guarantee to capture the design rainfall depth for all events, but is aimed at achieving this objective for at least 90% of all such events.

BOX 11.5 Tank storage volume calculation: intermediate method, water conservation + surface water management, passive control

When:

$$0.33 < Y_R/D_N < 0.7$$

Then:

Total storage = $V_{SC} + Y_R$

Where:

$$V_{SC} = A\,R_d - 0.5\,(D_N - Y_R)$$

V_{SC} = storage required for surface water management (l)
A = contributing runoff area (m²)
R_d = design storm event rainfall depth (mm)
D_N = 5% of the annual demand (l) (**Box 11.3**)
Y_R = 5% of the annual volume (yield) (l) (**Box 11.2**)

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BOX 11.6 **Tank storage volume calculation: detailed method, water conservation + surface water management, passive control**

As stated earlier, where $D_N > 3.0\ Y_R$, (ie demand is more than three times the yield), the total tank storage volume should be:

Total storage is $V_{SC} = AR_d$

where:

R_d	=	design storm event rainfall depth (mm)
A	=	area of the collection surface (m^2)

Otherwise the following formula applies:

$$V_{SC} = \left[\frac{A\,(R_d - SP50 + Ad)}{1000 \times CP50}\right] + 1.0$$

where:

R_d	=	net rainfall depth of the design storm (mm) (ie design storm depth × design event filter and runoff coefficients)
$SP50$	=	the net rainfall depth that is served by a 1 m^3 storage tank (mm) (see calculation method below)
Ad	=	additional net rainfall depth allowance to cater for the uncertainty of storage availability for the design storm event (a function of Y_R/D_N) (mm)
A	=	roof area (m^2)
$CP50$	=	effective proportion of additional storage available for increasing the tank size from 1 m^3 to store the design rainfall depth
V_{SC}	=	tank size (m^3)

SP50

The *SP50* value is the annual average measure of the storage space available; for 50% of the time there should be less than this volume available for storage of a large event. The value of *SP50* is:

$$SP50 = \frac{1000\ Cs}{A}$$

where:

Cs is a coefficient which is a function of Y_R/D_N

Cs = 1.0, if $Y_R/D_N < 0.6$

or

$$Cs = -0.677\,(Y_R/D_N) + 1.40$$

if Y_R/D_N ratio is between 0.6 and 0.9 for AAR < 750 mm and $r > 0.35$

or

$$Cs = -0.847\,(Y_R/D_N) + 1.49$$

if Y_R/D_N ratio is between 0.6 and 0.9 for AAR > 750 mm and $r < 0.35$

where:

r	=	standard rainfall parameter from the FSR (1975); the rainfall ratio for the 1:5 year 1-hour/2-day rainfall depth.

Note: the difference in the *Cs* values are small and this hydrological regional refinement only has a small influence on the design tank storage volume.

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BOX 11.6 Tank storage volume calculation: detailed method, water conservation + surface water management, passive control

***Ad* (allowance depth)**

As *SP50* is the available storage available in the tank for 50% of the time, an extra allowance of storage is needed to ensure capture of 90% of all storms equal to or greater than the design rainfall depth. This extra allowance depth (*Ad*), measured in terms of rainfall depth, is defined as:

$$Ad = 31.06(Y_R/D_N)^2 + 15.08(Y_R/D_N) + 0.36$$

This value tends to zero as Y_R/D_N becomes very small. The normal range for *Ad* is between 10 mm and 40 mm.

CP50

The *CP50* value takes into account the fact that the effective storage volume provided is less than the actual storage. As Y_R/D_N increases, the storage provided becomes less and less effective in storing the runoff. The value of *CP50* is:

CP50 = 1.0 if Y_R/D_N ratio < 0.6

$$CP50 = -3.29\,(Y_R/D_N)^2 + 4.16\,(Y_R/D_N) - 0.3$$

if Y_R/D_N ratio is between 0.6 and 0.9 for AAR < 750 mm and $r > 0.35$

$$CP50 = -4.06\,(Y_R/D_N)^2 + 4.94\,(Y_R/D_N) - 0.5$$

or

if Y_R/D_N ratio is between 0.6 and 0.9 for AAR > 750 mm and $r < 0.35$

Note: the difference in the values *CP50* values are small, and this hydrological regional refinement only has a small influence on the design tank storage volume.

11.3.4 The detailed surface water management method – with active control

Most RWH systems are designed as passive systems, and the demand for active RWH systems is currently limited. However, as the advantages they bring becomes better understood, especially in situations where site management criteria focus on runoff volume control, it is likely that actively managed RWH systems will become more commonplace. There are three benefits of using actively managed systems over their passive counterparts. These are:

- storage volumes can be reduced when the Y_R/D_N ratio is > 0.7
- they can be used where Y_R/D_N is > 1.0
- the assumption of non-compliance of 30% of all residential properties is no longer needed where RWH systems are used for individual dwellings.

The method works on the basis that active control of the available storage volume in the tank ensures that the capture of the design event rainfall runoff can be guaranteed. The active management requires the tank to be drawn down every time the water level encroaches above the volume needed to store the design rainfall depth. However, this action cannot be taken as soon as this threshold is triggered, as this may mean that the system is discharging rather than storing the design rainfall during a flood event. Therefore discharge can only take place when its effect will not cause negative impacts on flood risk for downstream areas and drainage systems. For many site drainage systems, the critical duration of the storage system is more than a day, in which case the drawdown should be delayed for at least two days in order to minimise the effects of many such systems drawing down following an event. The longer the period before drawdown, the greater is the statistical risk of the design rainfall depth being only partially captured or not being captured at all. However, the probabilities associated with this are very small and the consequences in larger catchments are also small. Only where Y_R/D_N ratios are significantly higher than 1.0 is this issue worth examining in more detail.

Although this method is not dependent on the ratio of yield to demand, it is worth noting that where Y_R/D_N < 1.0 the emptying frequency will be relatively small, while if it is above this threshold then pump drawdown will occur fairly often. Pump drawdown will be more frequent as the ratio increases. This factor could influence the design of the trigger thresholds and the on and off pump settings.

In cases where Y_R/D_N < 1.0, the drawdown depth might be set to the equivalent to 5 mm of rainfall (**Figure 11.10**). However, where Y_R/D_N > 1.0 the drawdown might be increased to 10 mm of rainfall to minimise the frequency of pumping, and also to ensure there is a little more time during which the available storage exceeds the design rainfall depth requirement. It should be noted that when Y_R/D_N > 1.0, the tank will be very rarely empty and therefore the extra drawdown will not significantly impact on the water available for use.

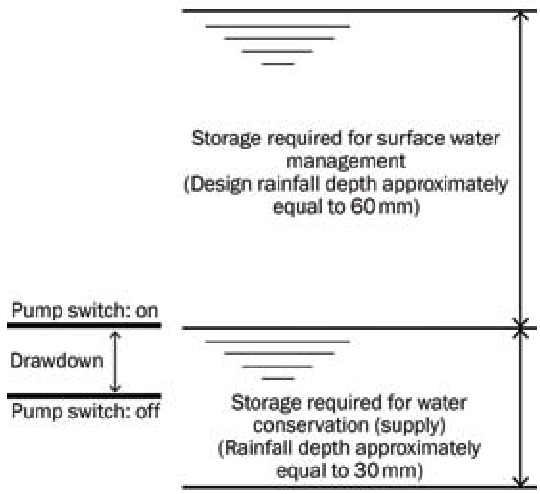

Figure 11.10 Rainwater harvesting tanks with active control for surface water management

Where RWH systems are designed to manage surface water runoff, they can contribute to all aspects of site drainage. For the surfaces served, they can meet the Interception criterion, contribute significantly to the volume reduction needed to meet the volumetric criterion and reduce the volume of temporary storage required to attenuate flows discharged from the site.

11.3.5 Interception design

RWH, whether designed for water conservation only or surface water management as well, provides benefits in delivering Interception for all connected surfaces – where demand from the system is regular and consistent through the year.

Where Y_R/D_N is significantly more than a ratio of 1.0 (and the system is not actively managed), then it will be ineffective for surface water management, but it can still be considered to provide Interception as it will prevent the first 5 mm of most rainfall events from creating runoff.

▶ Designing for Interception is discussed in **Section 24.8**.

11.3.6 Peak flow control design

RWH systems will only contribute to peak flow rate reductions during the period where upstream storage tanks are filling, that is when there is no runoff from the contributing surfaces. Once the tank storage is full, there will be no reduction in flow rates as it should be assumed that runoff then passes to the site drainage system. Unless the RWH system can be designed to guarantee to capture all events without overflowing (which is very unlikely), RWH systems cannot be assumed to contribute to a reduction in peak flow rate on a consistent basis, and therefore site conveyance design should not assume that any flow rate reduction is achieved. If RWH is a major site component in managing runoff, and it is felt that there are significant gains to be made in reducing the site conveyance capacity, then a detailed analysis of a continuous rainfall time series of 100–200 years would need to be carried out to justify the design of the site drainage where conveyance rates are reduced.

11.3.7 Volume control design for flood control

RWH systems can be designed to capture and retain the design rainfall event depth required for volumetric control (as set out in **Sections 11.3.3 and 11.3.4**).

The surface water management storage volume provided by the RWH systems will contribute to reducing the volume of attenuation storage required on the site. The critical duration of the design event for the site attenuation storage will be shortened due to the reduction in runoff volume delivered by the RWH system. The attenuation storage volume will be reduced by more than the amount of the RWH storage provided.

▶ Designing for attenuation storage is discussed in **Section 24.9**.

11.3.8 Exceedance flow design

RWH systems for surface water management are designed to capture a specific depth of rainfall. They therefore only contribute to extreme event flow management during the initial stages of extended extreme events and during high intensity, short duration rainfall when site drainage systems are overwhelmed while the rainwater tanks are still capturing and storing runoff.

Consideration should be given to the design of the RWH overflow and the subsequent discharge pathway. Where infiltration systems are used for disposal of excess water, then consideration should be given to the likely frequency and consequences of potential exceedance events.

11.4 TREATMENT DESIGN

There are two aspects with regards to RWH system treatment design:

1 the contribution of RWH systems to the control of pollution from site surface water runoff

2 the treatment of the collected rainwater so that it is suitable for non-potable domestic or other uses

11.4.1 RWH contribution to site runoff pollution control

Roof runoff is significantly less polluted than runoff from road surfaces. Nevertheless, roofs may still generate pollutants such as sediments, PAHs and metals due to atmospheric deposition and runoff entrainment. In some cases, particularly in commercial environments, the wash-off of roofing constituents such as copper and zinc is a particular issue. Where roof runoff is captured by the RWH system, any pollutants from the roof surface will be captured by the collection and filtration system. Maintenance of the system is essential to prevent debris, sediment and other pollutants that accumulate in the filters from being discharged downstream, and to ensure the long-term performance of the system.

By reducing the volume of runoff generated from the site, particularly for small events, RWH systems can directly reduce the pollutant load discharged to receiving waters. They are considered as an effective Interception component for the roof contributing to the system – whether designed for surface water management or water conservation (supply) only.

11.4.2 Treatment of collected runoff for use

RWH systems designed to BS 8515:2009+A1:2013 should deliver a water quality that is suitable for applications such as toilet flushing, washing machines and garden watering. Runoff that contains a high pollutant loading (eg sediments or heavy metals) may only be appropriate for use after treatment. The use of the harvested runoff will dictate the extent and type of treatment that should be provided. Disinfection may be required where site-specific risk assessment indicates the need for a specific water quality. Useful references on this topic include BS 8515:2009+A1:2013, BS 8595:2013 and a number of papers particularly those from Fewtrell and Kay (2007a, 2007b).

Rainwater harvesting water quality treatment measures include: pre-treatment, filtration, biological treatment and disinfection. Storing the water below ground can reduce the need for water quality treatment by keeping the water cool. Cool water has higher oxygen concentrations and prevents bacteria growth, and the lack of light prevents algal growth. Filters can be implemented pre or post storage. Treatment technology is developing rapidly as RWH system uptake and development increases, and is not covered further here.

11.5 AMENITY DESIGN

RWH systems provide indirect amenity value by supporting the resilience of developments and their landscape to changes in climate and water resource availability. Occasionally, they can also provide direct amenity value when implemented above ground, if designed with visual interest and/or integrated with landscape features and/or combined with educational initiatives. RWH systems can be made visually attractive, with considered engineering and landscape design input.

11.6 BIODIVERSITY DESIGN

RWH tanks do not have any inherent biodiversity value, but they can help to reduce flows on the downstream system, and this can help facilitate biodiversity delivery in those areas.

11.7 PHYSICAL SPECIFICATIONS

11.7.1 Pre-treatment and inlets

Primary screening devices are used to prevent leaves and other debris from entering the tank. Primary screening devices often have a wire mesh screen installed near the downspout. If leaves pose a problem, a leaf screen should be installed along the entire gutter length.

First flush devices can be designed to divert the first part of the rainfall away from the main storage tank. The first flush picks up most of the dirt, debris, and contaminants (eg bird droppings) that collect on the roof. Consideration will then be required as to where this first flush is safely treated and managed downstream.

11.7.2 Underdrains and outlets

RWH systems need either an inlet valve that closes flow into the container when it is full, or an overflow arrangement that conveys excess surface water runoff away from the building without causing damage. Erosion protection measures for the overflow should be provided as necessary.

11.8 MATERIALS

11.8.1 Rainwater harvesting tank structures

Most rainwater collection tanks are manufactured from plastics, concrete or steel. When selecting a material and product type, consideration should be given to:

- the potential need for protection of the tank materials against the corrosive effects of the stored water and any disinfectants used
- the tank service life
- resistance to flotation and potential restraint options
- structural design and installation complexity
- ease of maintenance if the system blocks or becomes contaminated in some way
- aesthetics (where the tank is visually accessible).

The storage of rainwater does not have to be in a traditional tank; the void space in sub-base material of a permeable paving system or within geocellular modular units, encapsulated within a robust, weldable, geomembrane can also be used.

▶ Geotextile and geomembrane specifications are presented in **Chapter 30**.

Tanks should be designed to prevent freezing during winter, and ingress of groundwater. Underground tanks should be properly designed and installed to withstand groundwater, earth and/or backfill pressures, surcharge loads, vehicular loading and flotation.

11.8.2 Collection and distribution systems

External pipework needs to designed to prevent freezing during winter.

Internal pipework needs to be distinguished from potable water pipework by using pipe materials which comply with the RWH code of practice BS 8515:2009+A1:2013.

11.9 LANDSCAPE DESIGN AND PLANTING

There are no landscape design aspects to the use of RWH systems unless the water is stored in a landscape feature.

RWH systems can be used to provide a supply of water for plant irrigation.

11.10 CONSTRUCTION REQUIREMENTS

RWH systems should be installed using safe construction methods, and manufacturers' guidelines should be followed in all cases.

Care should be taken to avoid cross-connections, and pipe marking is essential. Reference should be made to the Water Supply (Water Fittings) Regulations 1999. Guidelines are available in BS 8515:2009+A1:2013 on pipe markings, fittings and other construction guidance. Any buried tank should be designed by a structural engineer to ensure that it is suitable for the ground conditions in which it is installed.

Figure 11.11 Rainwater harvesting storage tanks during construction (courtesy British Precast)

Modern developments often have quite small gardens and RWH tanks are often located close to a building. Careful consideration of the structural impact on the building of the excavation and subsequent operation of the system needs to be taken. Consideration should also be given to requirements for structural support (eg using appropriate concrete backfill around the unit). Flotation risk during periods of extended wet weather should also be checked.

The operation of the tank overflow when the system is full (including the frequency, volume and impact of spills) needs to be considered and designed to avoid damage or nuisance.

Surface water should not be diverted to the RWH system until the catchment area and overflow area have been stabilised.

- ▶ More detail on construction activities and the programming of construction activities is provided in **Chapter 32**.
- ▶ Generic health and safety considerations are discussed in **Chapter 36**.

11.11 OPERATION AND MAINTENANCE REQUIREMENTS

Any property with an RWH system installed should be provided with appropriate information as to what equipment has been installed, its purpose, its operation and maintenance requirements, the actions needed to address any potential failure and the expected performance of the system. Information on the options for external maintenance support should also be provided.

Most systems require periodic checking and maintenance to ensure trouble-free and reliable operation. There are wide differences in the extent of maintenance required for different systems, and manufacturers' guidelines should always be followed. **Table 11.6** provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

Maintenance requirements are largely dependent on the runoff source and the runoff use (and thus treatment processes provided). This will range from weekly input through to rare intervention. Routine inspection of the filter system at quarterly annual intervals is advised, even if they do not appear to need specific intervention. Pumps need very little attention, but their design life is generally regarded as only being 10 years. Where automatic provision of potable water occurs (if and when rainwater is either not available or the system has failed), it is useful to have sensor warnings relayed in such a manner as to inform the user of the current status of the system.

RWH systems should be designed so that when there is an absence of rain, or a need to disconnect the system for maintenance or repair, that potable water is safely available for all appliances to avoid inconvenience.

Tanks should be accessible for internal inspection, and the cover should preferably be lockable. For more guidance on operation and maintenance of RWH systems, see BS 8515:2009+A1:2013.

The maintenance responsibility for an RWH system is usually with the owner of the property, but any communal systems require the participating community to be informed of the system, as detailed, but also be provided with information of who the organisation is that is maintaining the system and any financial commitments and any legally binding maintenance agreement.

TABLE 11.6 **Operation and maintenance requirements for RWH systems**

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Inspection of the tank for debris and sediment build-up, inlets/outlets/withdrawal devices, overflow areas, pumps, filters	Annually (and following poor performance)
	Cleaning of tank, inlets, outlets, gutters, withdrawal devices and roof drain filters of silts and other debris	Annually (and following poor performance)
Occasional maintenance	Cleaning and/or replacement of any filters	Three monthly (or as required)
Remedial actions	Repair of overflow erosion damage or damage to tank	As required
	Pump repairs	As required

11.12 REFERENCES

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Statutes

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BS 8542:2011 *Calculating domestic water consumption in non-domestic buildings. Code of practice*

BS 8595:2013 *Code of practice for the selection of water reuse systems*

The Water Supply (Water Fittings) Regulations 1999 (No.1148)

The Private Water Supplies Regulations 2009 (No.3101)


Image courtesy Arup

12 GREEN ROOFS

Contents

Chapter 12

Green roofs

This chapter provides guidance on the design of green roofs – that is, roofs with a vegetated surface that provide a degree of retention, attenuation and treatment of rainwater and promote evapotranspiration.

12.1 GENERAL DESCRIPTION

Green roofs are areas of living vegetation, installed on the top of buildings, for a range of reasons including visual benefit, ecological value, enhanced building performance and the reduction of surface water runoff. Types of green roof can be divided into two main categories:

- Extensive roofs, have low substrate depths (and therefore low loadings on the building structure), simple planting and low maintenance requirements; they tend not to be accessible.
- Intensive roofs (or roof gardens) have deeper substrates (and therefore higher loadings on the building structure) that can support a wide variety of planting but which tend to require more intensive maintenance; they are usually accessible.

A blue roof is a roof design that is explicitly intended to store water. This storage can be designed as attenuation storage (with water released in a controlled manner), as storage for use such as irrigation (potentially of adjacent green roof areas), cooling water (for use in reducing the temperature of the roof on hot days, or for internal cooling plant) or non-potable use within the building, and/or for recreational opportunities. Blue roofs can include open water surfaces, storage within or beneath a porous medium or modular surfaces, or below a raised decking surface or impermeable cover. Green roofs that include reservoir storage zones beneath the growing medium could also be termed “blue roofs”. Blue roofs are not considered in detail in this chapter as they are, essentially, equivalent to other components described in this manual. The key design considerations are the structural capacity of the roof to deal with the extra loadings and the waterproofing required to protect the building.

Although green roofs are generally more expensive than conventional roofs to construct and maintain, they can provide many long-term benefits. The vegetated cover assembly should be compatible with and designed to protect the underlying roof waterproofing materials. The design life of the roof waterproofing can be extended by protecting the waterproofing from mechanical damage, shielding it from ultraviolet radiation, and buffering temperature extremes.

Green roofs can improve the thermal performance of buildings, potentially reducing building energy costs, due to the plants and substrate cooling the roof through evapotranspiration during summer months. Winter insulation properties are dependent on the amount of water held by the roof, and in wet winters such as in the UK, gains will tend to be low. Green roofs will help combat the urban heat island effect where there is a sufficient number in an urban area, as well as contributing to improved air quality by capturing dust particles.

▶ Detailed UK guidance for green roofs is provided in Early *et al* (2007), The Greenroof Centre (2011) and GRO (2014).

A green roof consists of a system in which several materials are layered to achieve the desired vegetative cover and drainage characteristics. Design components vary depending on the green roof type and site constraints, but typically include the elements shown in **Figure 12.1**.

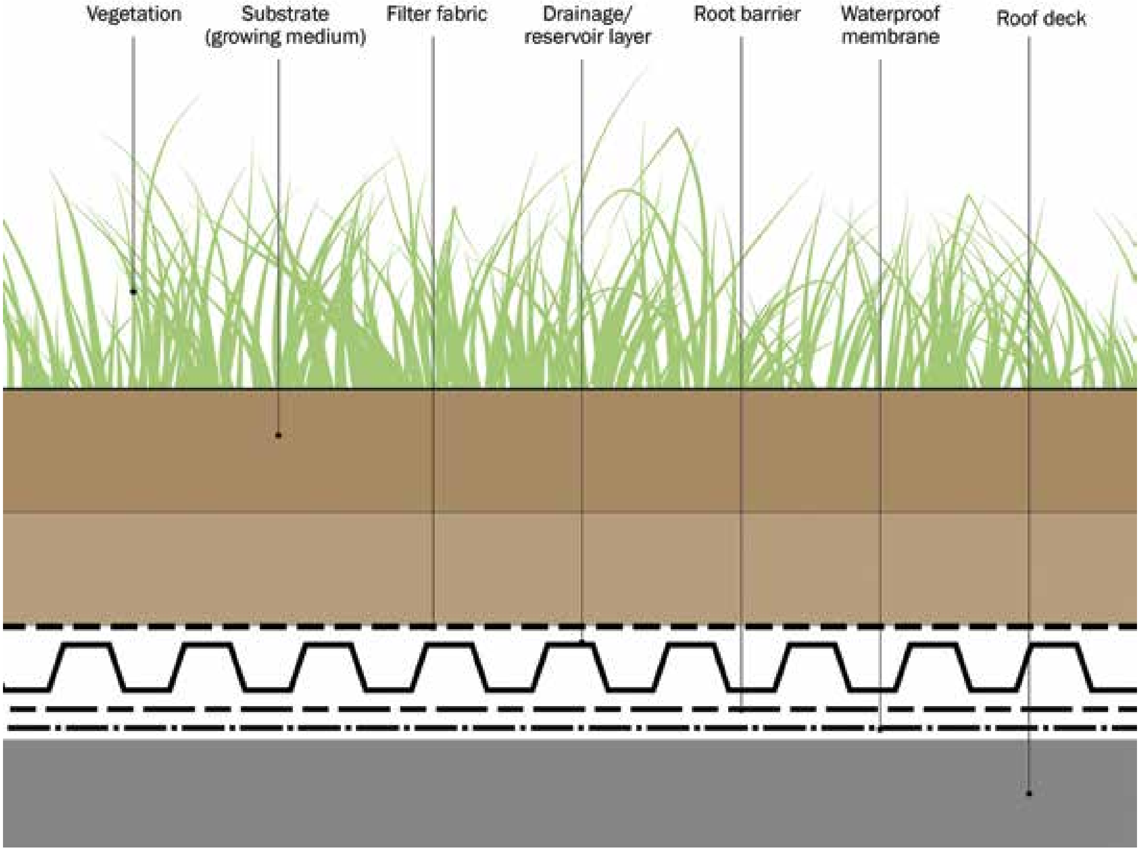

Figure 12.1 Section showing typical extensive green roof components

As mentioned earlier, there are two main types of green roof:

Extensive green roofs – These systems cover the entire roof area with hardy, slow growing, drought tolerant, low maintenance plants (eg mosses, succulents, herbs, grasses) often enhanced with wildflowers. Planting often establishes more slowly, but the long-term biodiversity can be of high value. They are only accessed for maintenance and can be flat or sloping. Extensive green roofs typically comprise a 20–150 mm thick growing medium and can be further divided into "single-layer" systems (which consist of a single medium designed to be free-draining and support plant growth), and "multi-layer" systems that include both a growing medium layer and a separate underlying drainage layer. They are lightweight and low cost to maintain, and can be used in a wide variety of locations with minimal intervention. They are often suitable for retrofit on existing structures due to their light weight. Biodiverse extensive green roofs are often planted with a mix of species supported by a range of soil depths.

Intensive green roofs (or roof gardens) – These are designed to sustain more complex landscaped environments that can provide high amenity or biodiversity benefits. They are planted with a range of plants including grasses, shrubs and/or trees, either as ground cover or within planters, and may also include water features and storage of rainwater for irrigation (ie blue roof elements). They are usually easily accessible, as they normally require a fairly high level of regular maintenance, and in some cases they are made accessible to the public. Intensive roofs have a deeper substrate, with >150 mm growing medium, and therefore impose greater loads on the roof structure.

Green roofs with substrate depths of 100–200 mm tend to be semi-intensive roofs, and can include characteristics of both extensive and intensive roofs, with plants that include shrubs and woody plants. Irrigation and maintenance requirements of this type of roof will be dependent upon the plant species chosen for the roof. There are also various combinations of green roof that combine both types in a single roof system.

A comparison of the main differences between extensive and intensive green roof systems is given in **Table 12.1**.

Figure 12.2 The Savill Garden extensive green roof

Figure 12.3 British Horse Society sedum blanket (courtesy Sky Garden)

Figure 12.4 Examples of accessible green roof with intensive and extensive planting, Bishops Square, London

TABLE 12.1 Comparison of extensive and intensive green roof systems

	Extensive green roof	Intensive green roof
Access	Not usually accessible	Accessible as public space or garden
Growing medium	Thin growing medium 20–150 mm	Deeper growing medium
Irrigation	Only during plant establishment	Occasional to frequent
Maintenance	Minimal to none	Low to high
	Advantages ▪ lightweight ▪ suitable for roofs with slope of up to 1 in 3 ▪ little or no need for irrigation and specialised drainage systems ▪ often suitable for retrofits ▪ little management of vegetation ▪ relatively inexpensive ▪ attractive to pioneer species colonisation, which can lead to a more biodiverse long-term ecosystem ▪ can support arrested pioneer communities, which are important for nature conservation **Disadvantages** ▪ more stressful conditions for plants, leading to lower potential diversity and associated biodiversity ▪ limited insulation provision ▪ limited surface water retention benefits ▪ limited aesthetic benefits	**Advantages** ▪ more favourable conditions for plants, leading to greater potential diversity of plants and habitats ▪ good contribution to thermal performance of the building ▪ can be made very attractive ▪ often accessible, with opportunities for recreation and amenity benefits ▪ good surface water retention capacity **Disadvantages** ▪ greater loading on roof structure ▪ need for irrigation and drainage systems requiring energy, water, materials ▪ higher capital and maintenance costs

12.2 GENERAL DESIGN CONSIDERATIONS

The successful design of a green roof will require collaboration between structural engineers (with particular respect to the structural capacity of the building to withstand the imposed loads), architects, landscape architects, ecologists, horticulturists and drainage engineers. It also requires consideration of the maintenance that will be required. Access to undertake the construction and maintenance easily and safely should be a high priority in designing the roof.

▶ Health and safety risk management design is discussed in **Chapter 36**.

Important design considerations include:

- accessibility requirements
- biodiversity objectives
- amenity/aesthetic objectives and desired visual impact
- the saturated weight of the system and the load-bearing capacity of the underlying roof deck and structure
- other imposed loads, including maintenance loadings and snow cover
- the need for integration of rooftop equipment, such as vents, air-conditioning systems, solar panels and/or RWH systems

- the root penetration resistance of the waterproof membrane or dedicated root protection layer
- resistance to wind shear and negative (uplift) wind pressures
- management of drainage
- growing medium
- suitability of plants
- maintenance management skills, equipment and time input.

12.3 SELECTION AND SITING OF GREEN ROOFS

Green roofs can be used on a variety of roof types and on any property size. They can be applied to a range of rooftop slopes, but steeper pitches will normally mean that less storage capacity is available, and the water drains away faster, unless the underlying drainage layer is specifically designed to capture and control flows. The greater the volume of water stored, the greater the potential loadings on the building – which may be an important design consideration.

Figure 12.5 Domestic green roofing, Swansea (courtesy Sky Garden)

The environmental parameters at the location where a green roof is to be installed have to be considered in the design process. The height of the roof, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact on the choice and suitability of planting. The general climate of the area and the specific microclimate on the roof should also be considered. Views to and from the roof may also determine where certain elements are located for maximum effect (**Section 12.6**). Ecological considerations include the bioregion in which the roof lies, the existing habitats (including any green infrastructure or other ecological networks) and the objectives of any local biodiversity strategies. Planning objectives may also be relevant (**Chapter 7**).

Green roofs can be easily retrofitted providing there is sufficient structural capacity in the roof to support them, and provided that suitable and robust waterproofing can be installed. With careful choice of materials, lightweight systems can be designed to suit most buildings.

Many new buildings will be able to accommodate green roofs with little or no increased strengthening because of the current requirement to provide thermal mass, in order to comply with Part L of the Building Regulations. Even on single ply roof waterproofing systems where ballast is not normally required, the increase in load from a green roof is unlikely to exceed 20%. Because of structural and other requirements in British standards and codes of practice, it is possible that an increase in load of this magnitude could be accommodated without increasing the structural capacity of the roof.

Lightweight industrial buildings may not have sufficient structural capacity to support a green roof, and this can lead to increased costs where the building has to be reinforced. However, the cost of the green roof and extra structural provision can be offset against long-term savings in the requirements for surface water attenuation storage at ground or below-ground level (The Greenroof Centre, 2011) and the improved thermal performance of the building.

Green roofs can be used together with RWH systems, although the yield from the roof will be significantly lower than for conventional roofing materials (**Chapter 11**).

12.4 HYDRAULIC DESIGN

12.4.1 General

Although green roofs absorb most of the rainfall that they receive during frequent events, there will always be a need to discharge excess water to the building's drainage system. The hydraulic performance of green roofs once saturated tends to be fairly similar to standard roofs. Therefore, the hydraulic design of green roof drainage should follow the advice in BS EN 12056-3:2000. Useful information is also provided in BS 6229:2003. Detailed guidelines for the planning, execution and upkeep of green roof sites are contained within GRO (2014).

Green roofs act a little like ordinary pervious surfaces, particularly intensive roofs with significant depths of substrate. However, this similarity reduces for roofs with shallower substrate and steeper gradients, which only tend to attenuate runoff during small or initial stages of an event.

Hydraulic design for green roofs should consider two aspects of their performance:

- how the roof is likely to behave during an extreme storm (and its potential contribution to meeting the hydraulic standard of service for the whole site drainage system), which is likely to be limited
- how the roof is likely to perform through the year, with a focus on the reduction of runoff volume for the majority of rainfall events (ie Interception).

12.4.2 Interception design

The performance of green roofs in terms of reducing or preventing the runoff from normal rainfall events is usually very significant in the summer due to the evapotranspiration processes and temporary storage provided by the roof.

All green roofs can be assumed to meet Interception requirements in the summer, based on their retention of 5 mm of rainfall. However, roofs are likely to struggle to meet Interception requirements during cold, wet winter periods when they are likely to be saturated for much of the time. The amount of rainfall that can be absorbed by a green roof before runoff takes place is very dependent on antecedent conditions. Thus, any assumptions regarding green roof performance during design storms should take a conservative position and consider whether the event is in summer or winter. Only an extended time series analysis will result in a reasonably accurate assessment of its likely performance. Any model should reflect the characteristics of the proposed green roof, and this might require calibration against observed data, as there are currently no modelling tools available which specifically represent green roof runoff. Evidence of green roof performance in reducing runoff from rainfall events is set out in **Box 12.1**.

It is uncommon to link a green roof to an RWH system, but in some circumstances this may be very beneficial (eg if the volume of runoff from the site has to be minimised and the demand for non-potable water is limited compared to the roof area). The colour of water collected from a green roof may preclude its internal use within the building, but it will be more suitable for irrigation.

▶ For guidance on RWH system design, see **Chapter 11**.

BOX 12.1 Reported evidence of Interception delivered by green roofs

Table 12.2 summarises the results of research into the performance of green roofs in reducing runoff frequencies and volumes.

Table 12.2 Summary of available evidence of performance of green roofs

Reference	Interception provided by green roofs[1]	Substrate depth
GSA (2011)	12.5–19 mm (USA)	Substrate depth 75–100 mm
Stovin *et al* (2012)	About 12–15 mm (estimated based on 100% retention of rainfall for 1:1 year, 1 hour event in Sheffield, UK and 72% retention for 1:1 year 24 hour event)	80 mm substrate
Fassman-Beck and Simcock (2013)	About 20 mm (most frequent result was 0 mm runoff for events up to 20 mm)	100–150 mm substrate
Paudel (2009)	16.5 mm (Detroit, Michigan, USA)	100 mm substrate
Martin (2008)	About 10 mm (Ontario, Canada)	100 mm substrate

Note

1 ie no runoff for majority of events up to these depths.

Martin (2008) reported that the reduction in depth and frequency of runoff from a green roof with 100 mm of substrate is similar to that of a naturally vegetated catchment. For the majority (70–80%) of rain events there is no runoff from green roofs (**Figure 12.6**) but for about 10 out of approximately 100 rain days a year green roofs have a response that is more similar to an impermeable surface (demonstrating the shift towards impermeable runoff characteristics when the substrate is saturated).

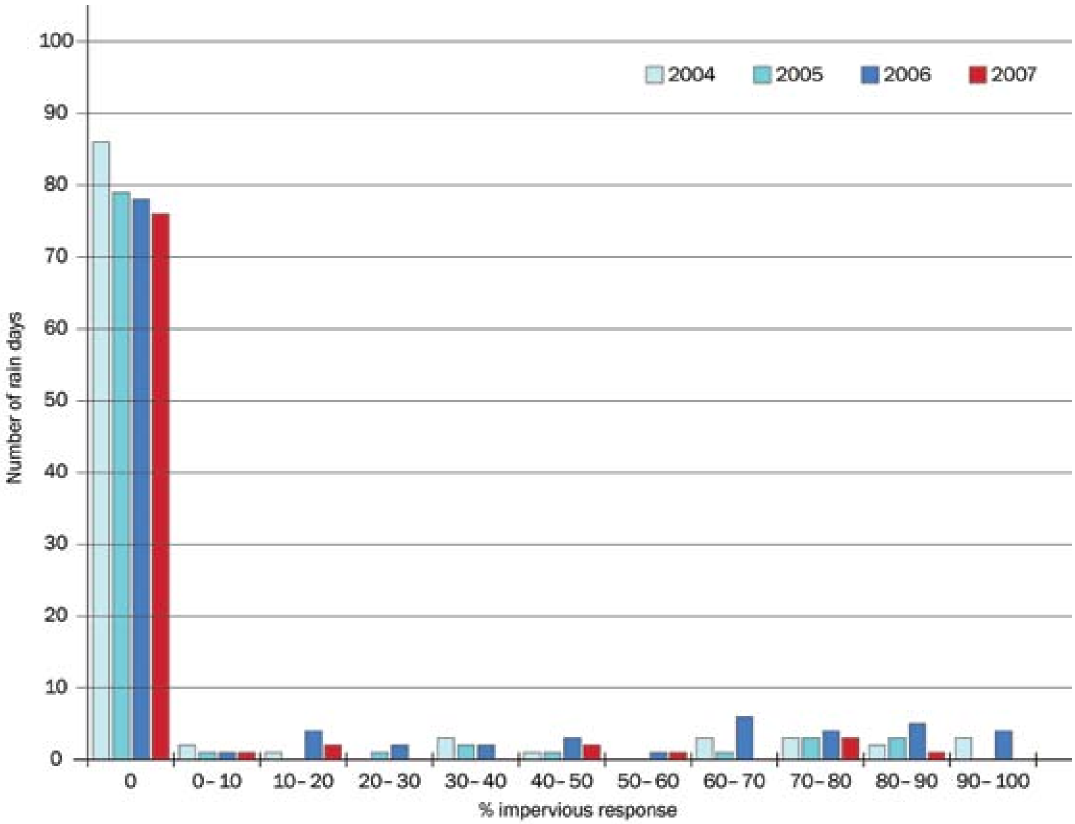

Figure 12.6 Distribution of runoff response (0% imperviousness means no runoff) (from Martin, 2008)

12.4.3 Peak flow control design

Green roofs can provide benefits in terms of reducing peak flow rates to the site drainage system – principally for small and medium-sized events. Their impact tends to be most significant in summer, where intense short duration events may generate very little runoff from the roof.

The reduction in the volume of runoff from a green roof for an extreme event is unlikely to impact on downstream attenuation storage requirements. Critical duration events for developments served by SuDS are commonly of the order of 12 to 36 hours, which tend to be representative of autumn and winter conditions, when reductions in runoff volumes from green roofs are likely to be small.

The depth of rainfall that will be stored in any rainfall event is a function of the antecedent soil moisture, the soil depth, the roof gradient and any specific storage provision designed within the drainage layer. The proportion of runoff from a green roof will increase as the duration and depth of the storm increases and the attenuation effects provided by the roof will reduce.

Where the design of the downstream drainage system (eg attenuation storage volumes and conveyance capacities) is linked to the green roof performance, then the benefits should be explicitly determined using modelling or evidence-based information. Attenuation can only be guaranteed if it is specifically included within the design as part of the drainage layer (and with the potential use of throttled outlets).

The storage characteristics of blue roofs will only be a function of the hydraulic controls at the outlet of the system. Although they can be designed to attenuate flows, any volumetric reduction will be limited to evaporation. The performance of a blue roof is more predictable than a green roof, as it usually constitutes a standard arrangement of attenuation storage and throttled outlets.

12.4.4 Volume control design

There is a growing body of evidence that green roofs considerably reduce the volume of runoff in warmer periods when the soil moisture deficit is high. The type of plants used and soil depths will influence evapotranspiration rates and available potential storage in the soil. Sedum roofs, due to the nature of the plants, tend to conserve water and have lower evapotranspiration rates during hot dry conditions (Stovin *et al*, 2012). The rate of evapotranspiration also depends on the volume of water stored (ie available) on the roof. If detailed modelling of roofs is carried out to assess runoff volume reduction accurately, then the model needs to incorporate an evapotranspiration rate relevant to the planting group, and a soil store component which adjusts the evapotranspiration rate with the volume of water stored. The rate of evapotranspiration is often assumed to be 3 mm/day in summer and 0 mm/day in mid-winter, but this may be lower for sedum roofs.

Blue roofs can also provide a reduction in the volume of runoff due to evaporation, and this process will be enhanced due to the solar warming of the water because of its shallow depth and exposed location. This is likely to be more significant in climates warmer than that of the UK.

12.4.5 Exceedance flow design

Every roof structure and all roof drainage design should consider the impact of events that are greater than the design event, and the risks associated with exceedance flows should be assessed and managed in an appropriate and safe way, to protect people and property. As wash-off of material could take place from green roofs, it is also important to assess potential failure mechanisms and their possible impacts. This assessment should then result in mitigation by either design adaptations or provision of further mitigation features.

12.5 TREATMENT DESIGN

The substrate used in the construction of green roofs should not add pollutants to the rainfall that percolates through it in a way that some traditional roofing materials (eg copper) can. The pollutant hazard will only be dependent on atmospheric pollution and will therefore tend to be lower than from hard surfaces.

Through a variety of physical, biological and chemical treatment processes, within the soil and root uptake zone, which filter airborne pollutants and pollutants entrained within rainwater, green roofs can help to reduce the amount of pollution delivered to the local drainage system and, ultimately, to receiving waters. Green roofs can provide further benefits in terms of moderating the temperature of the runoff (runoff from impervious surfaces can be very warm during summer months, and high temperature discharges can have negative effects on receiving water body ecology).

12.6 AMENITY DESIGN

Green roofs can be used to provide valuable amenity if the roof is intended to be accessible or is overlooked. They can improve the roofscape for the surrounding community of office occupiers as well as users of the green roof space itself, with the variety of planting and habitats creating a more colourful, aesthetically pleasing and natural environment, particularly in dense urban areas (**Figures 12.7** and **12.8**). Blue roofs tend to be constructed below the open space areas on podium decks, so the amenity value will be defined by the aesthetics and use of this space. The design of green roofs for amenity should follow standard industry practices for public spaces and accessible roof areas. They can also be integrated with rainwater harvesting to provide a source of water for landscape irrigation or other non-potable uses.

Figure 12.7 Green roof bus stop, Dundee City Centre (courtesy University of Abertay)

Figure 12.8 Green roof bike shelter at Six Acres Estate, Islington, London (courtesy Green Roof Shelters)

CASE STUDY 12.1 Kanes Food, Evesham

Figure 12.9 Kanes Food wildflower green roof (courtesy Sky Garden)

A new salad factory in rural Worcestershire was required to have minimal impact and blend seamlessly into the contours of the surrounding Cotswold Hills. Therefore, the curved roof was topped with a 6000 m^2 wildlife blanket, consisting entirely of species of native provenance (80 species sown).

Green roofs can be designed to deliver on a range of amenity principles including:

- climate resilience – through improved building thermal efficiency, reduced energy demand and reduction of the urban heat island effect
- improved air quality – via the absorption of carbon dioxide, some air pollutants and dust
- reduced noise levels – due to extra acoustic dampening
- increased building service life, and enhanced sales or rental value due to the high aesthetic appeal, reduced energy costs and the building is associated with sustainable design and social responsibility.

Green roofs have also been shown to enhance the performance of photovoltaic panels where they are used in combination (Zinco, 2011, and The Biosolar Roof Project: **www.biosolarroof.com**).

12.7 BIODIVERSITY DESIGN

Green roofs can be designed to provide high ecological value. They can help to conserve valuable habitat and biodiversity and provide an oasis of life in an otherwise sterile urban environment. They can also contribute to networks, clusters and corridors of green space that connect previously fragmented habitats.

Even in densely populated areas, birds, bees, butterflies and other insects and invertebrates can be attracted to green roofs and gardens at great heights, which provide them with nesting and foraging habitats (Johnston and Newton, 2004). Green rooftops can provide a micro “stepping stone” habitat for birds and insects, connecting natural isolated habitat pockets with each other, or provide an “island” habitat above those at ground level. Green roofs can be specifically designed to resemble endangered ecosystems or habitats, by choosing appropriate layouts, designs and planting schemes that will provide the desired habitat for the species concerned. Compared to conventional roofing, the soil and vegetation on a green roof should also reduce the risk of raised runoff temperatures. This is particularly important where the runoff is into sensitive water bodies.

A green roof designed for minimal maintenance means that habitats are less likely to be disturbed and, with appropriate design, they can provide habitat for a wide range of vulnerable plants and ground-nesting birds. Habitats can be further enhanced by incorporating artificial nesting sites, such as bat boxes, bird boxes, bee hives/hotels.

Gedge *et al* (2012) describes how green roofs can be designed with invertebrates in mind. It suggests that by doing this the overall ecological value of the green roof can be increased, and other benefits, notably the attenuation of rainwater and evaporative cooling, can also be increased. The report reviews over a decade of research on the biodiversity of green roofs in London and Switzerland. It notes that it is possible to create arrested pioneer vegetation on green roofs, which is similar to some of the “open mosaic” habitats found on unmanaged brownfield sites. Brownfield sites, which are targeted for redevelopment by the planning system, often support rich assemblages of invertebrates. The loss of some brownfield sites can be mitigated, in part, by creating similar habitats on roofs.

The research in Switzerland found that extensive green roofs support a wide range of beetles, spiders and bees, including many red data book species (IUCN Red List of Threatened Species: **www.iucnredlist.org**). Varying the topography on the roofs in Switzerland meant that species associated with both bare dry areas as well as other species associated with more densely vegetated and damper mounds could occur together. In London, comparisons between sedum dominated roofs and “biodiverse” roofs with a wider range of plant species, showed that the number of invertebrate species on sedum roofs, though initially higher, fell over time as the roofs dried out, whereas the fauna of biodiverse green roof increased as the roofs matured. Both ubiquitous and specialist invertebrates are found on green roofs and a remarkably high percentage of species found (over 10%) were locally or nationally scarce or rare.

The guidance recommends that sufficient depth of substrate is used on green roofs (no less than 80 mm) and that the topography is varied in depth (typically between 80 and 150 mm) in order to provide a range of habitats for invertebrates (**Figure 12.10**).

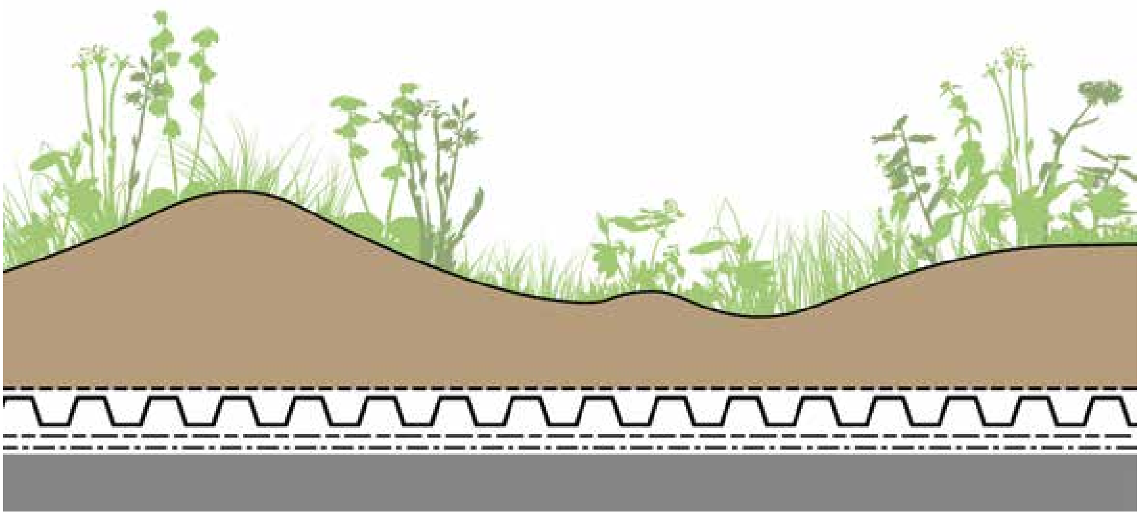

Figure 12.10 Biodiverse green roof with varied substrate depths (from Gedge *et al*, 2012)

The use of unscreened spoil or demolition waste is now discouraged as a growing medium because of problems with contamination and poor water holding characteristics. This does not mean that recycled materials cannot be used. They can be used if carefully selected and their properties evaluated for the proposed use. Normally, commercially available proprietary substrates are recommended, supplemented in places with sand, stone, untreated timber or other materials to provide habitat diversity. It is recommended that biodiverse green roofs are seeded and plug planted with native drought-tolerant wild flowers. Self-colonisation in urban locations is no longer recommended, due to problems with invasive non-native species, such as Conyza. Water bodies or ephemerally wet areas can be provided at roof level in the form of a pond, undulations or merely as a series of water holding containers (**Figure 12.11**).

The addition of photovoltaic panels on a green roof can provide a complex habitat structure for eg black redstarts (*Phoenicurus ochruros*), and microhabitats for invertebrates.

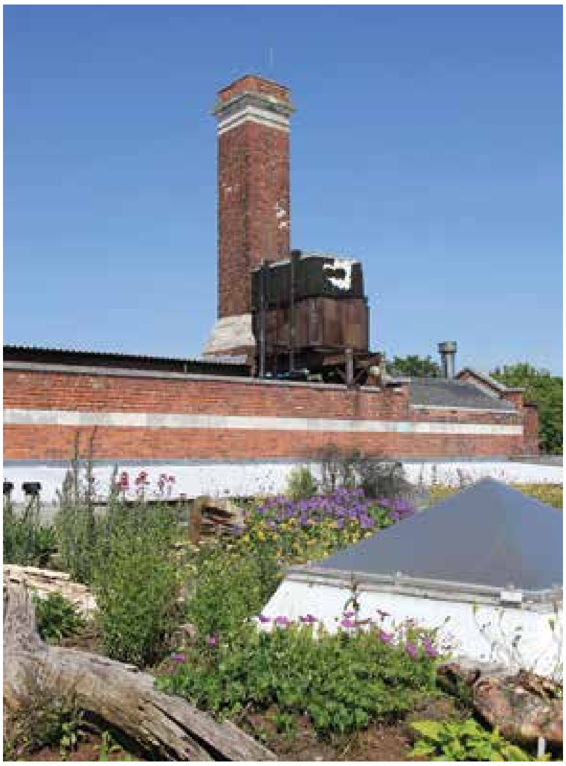

Figure 12.11 Biodiverse green roof, Unicorn Grocery, Manchester (courtesy Unicorn Grocery)

CASE STUDY 12.2 **Abbey Hive, Camden, London (from Gedge *et al*, 2012)**

Figure 12.12 Abbey Hive biodiverse roof (courtesy Clare Dinham)

A biodiverse roof was installed on the Abbey Hive community building. The roof covered 200 m^2 and is split over three levels, including features such as:

- low nutrient, free draining substrate of varying depths (typically 80–150 mm)
- areas of exposed bare ground
- seeded and plug planting using a variety of species beneficial to invertebrates, such as bird's foot trefoil (*Lotus conriculatus*), lady's bedstraw (*Galium verum*) and selfheal (*Prunella vulgaris*)
- locally collected wildflower seeds, such as viper's bugloss (*Echium vulgare*)
- log piles and sandy banks, providing areas for invertebrates to bask, burrow and hunt for prey.

CASE STUDY 12.3 **Sharrow School, Sheffield**

Figure 12.13 Sharrow School green roof (courtesy The Green Roof Centre)

The 2000 m^2 roof has been designed to represent the variety of habitats found in Sheffield – Peak District limestone grassland, wildflower meadows, urban brownfield and a wetland area with a small pond. Bird tables and insect feeders attract wildlife, and a weather station and webcam have been installed to provide educational and research opportunities.

The substrate consists of over 200 tonnes of crushed brick, organic greenwaste and limestone. Some areas were planted with shrubs and flowers while other areas were left to grow naturally.

12.8 PHYSICAL SPECIFICATIONS

12.8.1 Fire resistance

The fire resistance of green roofs should be considered. All openings, vents etc should be protected or surrounded by non-vegetative materials such as pavers or pebbles or other proprietary fire-retardant products. The roofs must have adequate resistance to the external spread of fire as required by Building Regulation B4 (ODPM, 2002) or Regulation 12 in Scottish Government (2004). To achieve this, a risk assessment should be undertaken, considering factors such as the organic content of the substrate, the vegetation type and the effects of these on the spread of fire (Wilson *et al,* 2004). German authorities only consider extensive roofs to be fire resistant if:

- the substrate/soil is >30 mm deep
- the substrate/soil contains less than 20% organic matter
- there is a 1 m wide gravel or slab fire break every 40 m
- gravel strips are provided around all structures penetrating the roof (FLL, 2002).

▶ Detailed guidance is set out in the document DCLG (2013).

12.8.2 Insulation

No extra insulation is required for the successful establishment of a green roof, but designers often use the roof as an opportunity to improve the thermal efficiency of the building. Green roofs may be “cold” where an air gap separates the membrane from the insulation beneath, or “warm” where insulation covers the waterproof layer.

12.8.3 Roof pitch

To ensure the minimum finished fall of 1 in 80, as recommended for flat roofs in BS 6229:2003, falls should be designed to 1 in 40. Falls should be consistently graded, without deflections or depressions.

The construction effort and cost of green roofs tends to increase with roof pitch. For roofs steeper than 1 in 10, rapid runoff should be prevented by increasing the retention capacity of the system (using check dams or cellular storage structures). For roofs steeper than 1 in 5, specific design advice should be sought to determine appropriate steps that are required to:

- prevent soil slippage and erosion
- provide extra support with cross battens
- provide a raised grid structure to secure the plant growing substrate.

12.8.4 Roof support

The extra load imposed on the underpinning roof structure varies with the type of green roof, but it is typically within a range of 0.7–5.0 kN/m^2. Intensive green roofs with trees together with an imposed “crowd” loading can impose loads of up to 10 kN/m^2. The distributed load should account for a saturated soil (and snow loadings, if appropriate), and live loadings should account for maintenance staff and equipment, and visitors (if appropriate). Deeper planting beds can often be constructed over internal columns and walls where a higher overall loading capacity can be provided. The design of the supporting structure should only be undertaken by an experienced structural engineer.

Uplift pressures from wind are greatest at the corners of a roof, and these may be designated as vegetation-free zones with pavers used to prevent damage. However, green roofs are no more vulnerable to this threat than conventional roofing. Trees may require shielding from the wind and/or should be anchored. On tall buildings, higher wind speeds may increase water loss and/or damage plants through windburn, and may therefore prove a risk to the long-term survival or plant communities. Barriers (eg parapet walls) can be used to mitigate these effects.

12.8.5 Water storage and irrigation

Green roofs should be able to store water and not dry out too quickly. If this is not possible within the soil substrate, then additional forms of water storage in the base layer can be provided, or irrigation may be appropriate. Irrigation systems are generally not recommended for extensive roofs, due to the costs and operation associated with their implementation and management. However, they are often necessary for intensive roofs. If irrigation is required, base level irrigators that introduce water directly to the root zones via the drainage layer have the following advantages:

- Roots are encouraged to grow down into the deepest part of the soil medium where temperature and moisture conditions are most stable.
- A dry surface cover is maintained, thus discouraging the germination of weed seeds.
- Water losses due to evaporation are minimised.

However, if the system blocks, then it may need to be dug up which is likely to be costly.

More sustainable permanent irrigation systems include the use of air conditioning condensate or other readily-available non-potable supplies.

Provision might need to be made for supplemental irrigation during the first two growing seasons after installation to ensure plant survival, depending on the location and the types of plants being grown.

On blue roofs or mixed blue/green roofs, water can be stored for irrigation of the surrounding landscape by either active or passive irrigation systems.

12.8.6 Access and safe working

Stairways, perimeter barriers, safe paths and in some cases lighting and lifts, all built to the relevant standards, are required if the green roof is to be used by people, whether the public or maintenance staff. Appropriate provision of safety attachment points and other features should be used to provide a safe working environment.

12.8.7 Pre-treatment and inlets

There is no requirement for pre-treatment or inlets for a green roof unless irrigation water is being applied. Standard pre-treatment/inlet requirements will need to be considered for drainage on blue roofs.

12.8.8 Outlets

All types of outlet should be designed in order to minimise the risk of blockage, which could have serious consequences. They should also be easily accessible for seasonal cleaning and in case of blockage. Detailed guidance on the capacity and location of rainwater gutters and outlets is given in BS 12056-3:2000. Rainwater outlets should accept runoff from both the drainage layer and the surface of the system.

Outlets should be separated from the growing medium, preventing the invasion of plant growth and the entry of loose gravel, as shown in **Figure 12.14**. Outlets can include flow control systems designed to control flows into roof downpipes and thus deliver specific attenuation performance.

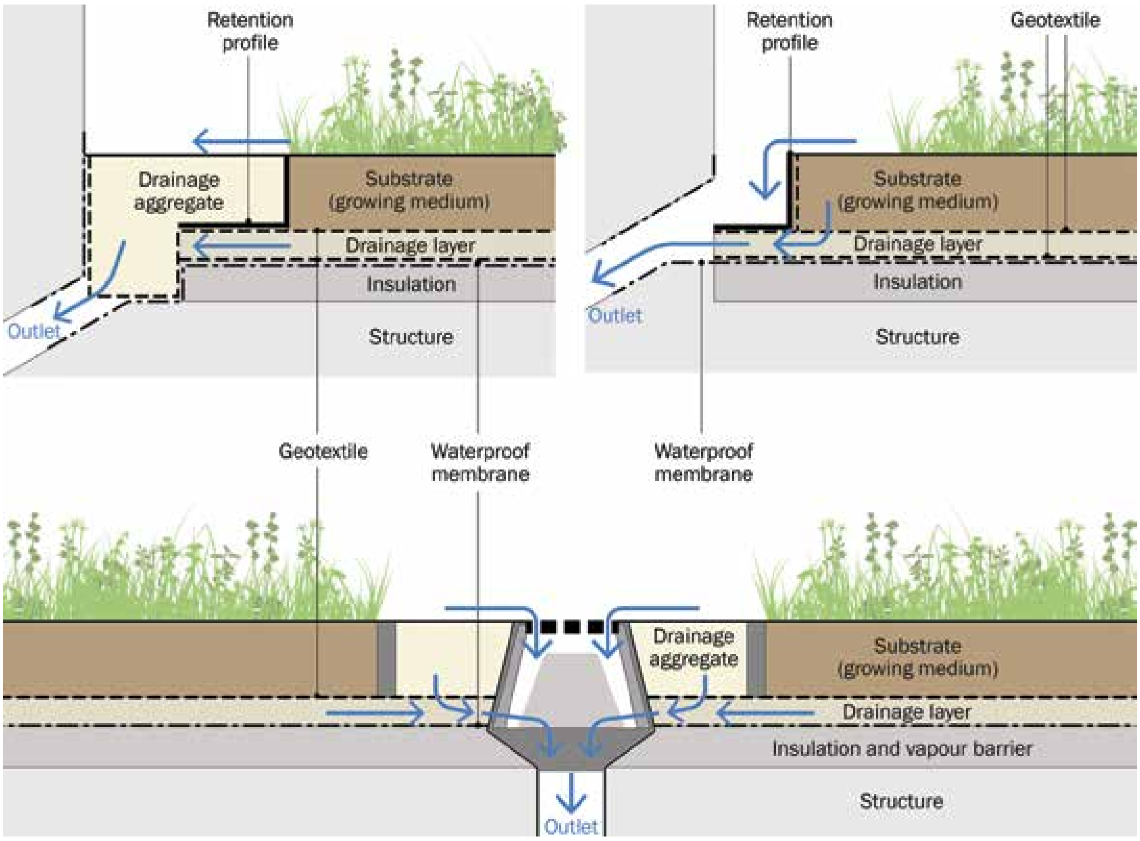

Figure 12.14 Example details of outlet from a green roof – subsurface outlet (top), and open outlet (bottom)

12.9 MATERIALS

Information on each of the material layers is provided in the following sections.

▶ Detailed information is provided by Early *et al* (2007), the Greenroof Centre (2011) and GRO (2014).

12.9.1 Waterproof membrane

A high quality, robust waterproofing layer is required and is a vital component of the system. Waterproof membranes can be made of a range of materials including reinforced polyvinyl chloride, synthetic rubber, thermoplastic polyolefins, high density polyethylene, modified asphalts and hypalon.

The waterproofing layer may need to be anchored to the roof to resist wind uplift forces if plastic sheeting is used. Waterproof membranes should be root resistant and should be adequately protected from temperature changes and mechanical damage to ensure that the integrity of the lower building fabric is retained. BS 6229:2003 should be referenced together with other relevant waterproofing specifications.

Care should be taken to ensure reliability of membranes, as repairs are difficult once the green roof is completed. It is therefore recommended that membranes are electronically tested for leaks, or flood tested, before the covering elements are installed.

12.9.2 Root barrier

Root barriers are used to prevent roots from damaging the waterproof membrane. Root barriers can often be avoided through the use of careful waterproofing and appropriate design. The waterproof membrane manufacturer should be consulted to determine whether or not a root barrier is required.

12.9.3 The drainage layer

Figure 12.15 Installing a green roof outlet with surface overflow (courtesy Clare Dinham)

The drainage layer is located over the waterproofing layer and underlies the entire green roof. Its principal function is to drain excess water from the roof, but it can be designed to retain specific volumes of water for attenuation, and/or retain some water for plants to draw on when rainfall is low. It connects to gutters and downpipes, typically via geocomposite/geocellular drainage systems that are lightweight and provide efficient drainage.

The layer should have sufficient flow capacity to carry the necessary volume of water from the roof. Flow capacity will depend on a number of factors, the principal ones being the hydraulic gradient and the hydrostatic pressure applied to the geocomposite. The performance specification of the proposed material should be checked against relevant European Standards (eg BS EN 13252:2001) for the hydraulic gradients and pressures relevant for the specific application.

A shallow layer of gravel or pebbles over a width of approximately 300–400 mm from the outside perimeter of the roof is often useful, providing protection for the vegetation from wind vortices, extra drainage close to outlets, fire control and access to the roof edges for maintenance (**Figure 12.15**).

12.9.4 Geotextile filter layer

Geotextiles prevent clogging of the drainage layer by separating it from the growing medium above. It should have zero breakthrough head (ie water discharges through it without building up on the upstream side) so that it does not impede the passage of water. It is essential to mark the position of the roof outlets before installing the protection layer, so that they can be easily located and the filter layer cut accordingly. Reliable detailing at points where the filter layer is penetrated, for example by pipework, and perimeter areas with durable protection is critical.

12.9.5 Soil or growing medium

The depth of soil medium and the material used should be selected to support the vegetation proposed. An important design consideration is balancing the benefits associated with greater depths of soil against the extra structural loadings that this imposes. Typically a minimum of 80 mm thickness is acceptable to give a reasonable variety of plants, although greater depths contribute to wind stability, increase insulation effect, increase rainfall storage and protect the roots from frost damage. The depths appropriate for various types of vegetation are summarised in **Table 12.3**.

Low density soils with good water retention and reasonable fertility are required, and mixtures of organic and mineral material (for example, recycled crushed brick or pumice) are suitable. Appropriate materials need to be:

- reasonably water permeable
- water and air retentive
- resistant to decay, heat, frost and shrinkage
- suitable in terms of nutrient content
- a good rooting medium.

Normal topsoil is too heavy and too nutrient rich for use on green roof systems and has a tendency to clog the filter layer. The growing medium should be carefully formulated so that it is light but provides for the oxygen, nutrient and moisture needed by the plants that the roof aims to support. An appropriate specification for soil for use on extensive roofs is provided in **Table 12.3**.

TABLE 12.3 Green roof substrate specifications (from GRO, 2014)

	Reference values	
Physical property	**Extensive**	**Intensive**
Particle size ≤ 0.063 mm (fines)	≤ 15% (by mass)	≤ 20% (by mass)
Particle size > 4.0 mm	≤ 50% (by mass)	≤ 40% (by mass)
Maximum water holding capacity (MWHC)	≥ 25% ≤ 65% (by volume)	≥ 45% (by volume)
Air content at MWHC	≥ 10% (by volume)	≥ 10% (by volume)
Water permeability	0.6–70 mm/min	0.3–30 mm/min
pH value	6.0–8.5	6.0–8.5
Organic content	≤ 65 g/1	≤ 90 g/1

12.10 LANDSCAPE DESIGN AND PLANTING

The rooftop microclimate is a difficult environment for plants to survive in, and the advice of a landscape architect or similar professional with experience of green roofs is essential. The vegetation has to deal with periodic rainfall alternating with hot and dry periods. Plants also have to contend with high winds and low winter temperatures (which is not ameliorated by the ambient heat stored in the ground).

To be able to survive, vegetation should have the following attributes:

- perennial or self-sowing
- drought tolerant, requiring little or no irrigation after establishment
- preference for well-drained soils
- rapid establishment
- self-sustaining, without the need for fertilisers, pesticides or herbicides
- ability to withstand heat, cold and high winds
- ability to tolerate poor soil
- low maintenance – needing little or no mowing or pruning

Some of these attributes may not be so relevant for intensive roofs where regular maintenance and irrigation can be provided, and where the depth of growing medium is less constrained. The choice of plants also depends on the other layers in the roof design (and vice versa) and on sun and shade conditions. In many cases there may be very good reasons to promote a wide range of plants, for example to improve water storage, improve evapotranspiration, enhance the aesthetics of the roof or encourage biodiversity. The use of a wider range of plants is dependent on other layers in the system and the accessibility or visibility of the roof. Claridge and Edwards (2012) suggest that planting a green roof with different species that have high water uptake rates under different soil moisture conditions can improve green roof performance. Suggestions for relevant plants with increasing depth of growing medium are given in **Table 12.4**.

TABLE 12.4 Planting for green roofs (from Dunnett, 2003)

Depth of growing medium	Accessibility and visibility of roof			
	Inaccessible/not overlooked	Inaccessible/visible from a distance	Inaccessible/visible from a close distance	Accessible
0–50 mm	Simple sedum/moss communities	Simple sedum/moss communities	Simple sedum/moss communities	Simple sedum/moss communities
50–100 mm		Dry meadow communities/low growing drought tolerant perennials, grasses and alpines, small bulbs	Dry meadow communities/low growing drought-tolerant perennials, grasses and alpines, small bulbs	Dry meadow communities/low growing drought-tolerant perennials, grasses and alpines, small bulbs
100–200 mm			Semi-extensive mixtures of low medium dry habitat perennials, grasses and annuals, small shrubs, lawn/turf grass	Semi-extensive mixtures of low medium dry habitat perennials, grasses and annuals, hardy shrubs
200–500 mm				Medium shrubs, edible plants, generalist perennials and grasses
> 500 mm				Small deciduous trees and conifers

Further planting guidance is provided by Early *et al* (2007), The Greenroof Centre and GRO (2014).

There are four basic methods of installing green roof vegetation:

- **Pre-grown vegetation mats:** These are pre-germinated mats that provide immediate full plant coverage and erosion control. These have minimal weed problems and require little maintenance, but may need some watering during the establishment period.
- **Plugs or potted plants:** These may provide more flexibility, but coverage takes longer, and erosion may be a risk. They will require watering and weeding during establishment.
- **Cuttings/sprigs:** These have to be hand planted, and require weeding, erosion control and watering initially.
- **Seeds:** These have to be hand or machine planted, and require weeding, erosion control and watering initially.
- **Self-seeding:** Green roofs can be left to colonise naturally.

Intensive green roofs can be landscaped and managed to suit local aesthetic and community requirements. Extensive green roofs tend to provide less conventional aesthetics. In practice, green roofs in city centres are not obvious to most passers-by, although they can be overlooked by high-rise buildings. Use of green roofs in suburban areas tend to use pitched roofs which are more visible.

12.11 CONSTRUCTION REQUIREMENTS

▶ Advice on constructing green roofs is provided in Early *et al* (2007), The Greenroof Centre and GRO (2014).

Correct application of the waterproof membrane is essential to the viability of the green roof. Quality control must be assured through the use of certified roofing procedures and an electronic water leakage test immediately following membrane application to ensure that the surface is impermeable.

Temporary ballasting of individual components may be required during construction to prevent uplift due to wind. The growing medium should be protected from over-compaction during construction, and mulch, mat or other measures to control erosion of the growing medium should be maintained until 90% vegetation coverage is achieved. The growing medium and separation fabric should be isolated from sedimentation during construction.

Safe access is required for construction of the green roof, and also for all activities in areas beneath the roof. Ideally, the roof should be installed when no follow-on trades need access to the roof after installation, in order to reduce the risk of damage.

- ▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

- ▶ Generic health and safety guidance is presented in **Chapter 36**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified and eliminated/reduced and/or controlled where appropriate.

12.12 OPERATION AND MAINTENANCE REQUIREMENTS

Intensive green roofs are likely to require regular inspection and maintenance. Grassed areas may require mowing weekly or fortnightly, plant beds may require weeding on a weekly or fortnightly basis during the growing season, and wildflower meadows may require annual mowing with the cuttings removed. Extensive green roofs should normally only require biannual or annual visits to remove litter, check fire breaks and drains and, in some cases, remove unwanted invasive plants. The most maintenance is generally required during the establishment stage (12 to 15 months), and this should usually be made the responsibility of the green roof provider. Maintenance contractors with specialist training in green roof care should be used, where possible.

Table 12.5 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required. Actual requirements will depend on the planting, the desired aesthetic and visual effect and the biodiversity objectives for the system. Maintenance specifications and schedules should therefore be specified for any individual green roof.

If mechanical systems are located on the roof, then spill prevention measures should be exercised to ensure that roof runoff is not contaminated. The mechanical system area should be bunded and provided with separate drainage.

All maintenance actions carried out at roof level must be in full compliance with the appropriate health and safety regulations, and particularly those specifically dealing with working at height. Training and guidance information on operating and maintaining the roof should be provided to all property owners and tenants. Safety fastenings will be required for personnel working on the roof.

Access routes to the roof should be designed and maintained to be safe and efficient, and walkways should always be kept clear of obstructions. Secure points for harness attachments should be provided when access near to the roof edges is required.

Specific maintenance needs of the green roof should be monitored and maintenance schedules adjusted to suit requirements.

TABLE 12.5 Operation and maintenance requirements for green roofs

Maintenance schedule	Required action	Typical frequency
Regular inspections	Inspect all components including soil substrate, vegetation, drains, irrigation systems (if applicable), membranes and roof structure for proper operation, integrity of waterproofing and structural stability	Annually and after severe storms
	Inspect soil substrate for evidence of erosion channels and identify any sediment sources	Annually and after severe storms
	Inspect drain inlets to ensure unrestricted runoff from the drainage layer to the conveyance or roof drain system	Annually and after severe storms
	Inspect underside of roof for evidence of leakage	Annually and after severe storms
Regular maintenance	Remove debris and litter to prevent clogging of inlet drains and interference with plant growth	Six monthly and annually or as required
	During establishment (ie year one), replace dead plants as required	Monthly (but usually responsibility of manufacturer)
	Post establishment, replace dead plants as required (where > 5% of coverage)	Annually (in autumn)
	Remove fallen leaves and debris from deciduous plant foliage	Six monthly or as required
	Remove nuisance and invasive vegetation, including weeds	Six monthly or as required
	Mow grasses, prune shrubs and manage other planting (if appropriate) as required – clippings should be removed and not allowed to accumulate	Six monthly or as required
Remedial actions	If erosion channels are evident, these should be stabilised with extra soil substrate similar to the original material, and sources of erosion damage should be identified and controlled	As required
	If drain inlet has settled, cracked or moved, investigate and repair as appropriate	As required

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified and eliminated, reduced or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is presented in **Chapter 36**.

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BS EN 12056-3:2000 *Gravity drainage systems inside buildings. Roof drainage, layout and calculation*

Construction (Design and Management) Regulations (CDM) 2015

Image courtesy Simon Bunn

13 INFILTRATION SYSTEMS

Contents

Chapter 13

Infiltration systems

This chapter provides guidance on the design of infiltration systems – systems that are designed specifically to promote infiltration of surface water runoff into the ground. This includes soakaways, infiltration trenches, infiltration blankets and infiltration basins.

- ▶ *Guidance on the suitability of using infiltration, testing and design methods is provided in Chapter 25.*
- ▶ *Appendix C, Section C.5.1 demonstrates how to design a residential soakaway.*

13.1 GENERAL DESCRIPTION

There are many different types of drainage component that can be used to facilitate infiltration. These include soakaways, infiltration trenches, infiltration blankets and infiltration basins. Bioretention systems and pervious pavement can also be designed to allow infiltration from their bases (**Chapters 18 and 20** respectively).

Infiltration can contribute to reducing runoff rates and volumes while supporting baseflow and groundwater recharge processes. The rate at which water can be infiltrated depends on the infiltration capacity (permeability) of the surrounding soils.

Soakaways are excavations that are filled with a void-forming material that allows the temporary storage of water before it soaks into the ground. Historically, small soakaways draining runoff from a single property were either filled with rubble or lined with brickwork and were sited below gardens and drives with no formal provision for access and inspection. Many small soakaways are now constructed with geocellular units available from builders' merchants pre-wrapped in geotextile. The geocellular units provide good overall storage capacity compared to rubble fill, and they allow the size of the structure required for any application to be minimised.

Larger soakaways may be constructed with perforated precast concrete manhole rings surrounded with granular backfill or using geocellular structures (**Chapter 21**). Concrete manhole soakaways have the advantage of access for inspection and maintenance (although any gravel surround cannot be inspected or easily maintained). When considering the use of geocellular systems, the long-term structural integrity, acceptance for adoption by the SuDS system asset owner/operator and the anticipated service life of the asset should be addressed.

Figure 13.1 shows the characteristics of a typical geocellular soakaway with pre-treatment for a larger system and **Figure 13.2** shows a precast concrete system. Alternative configurations for geocellular systems are described in **Chapter 21**.

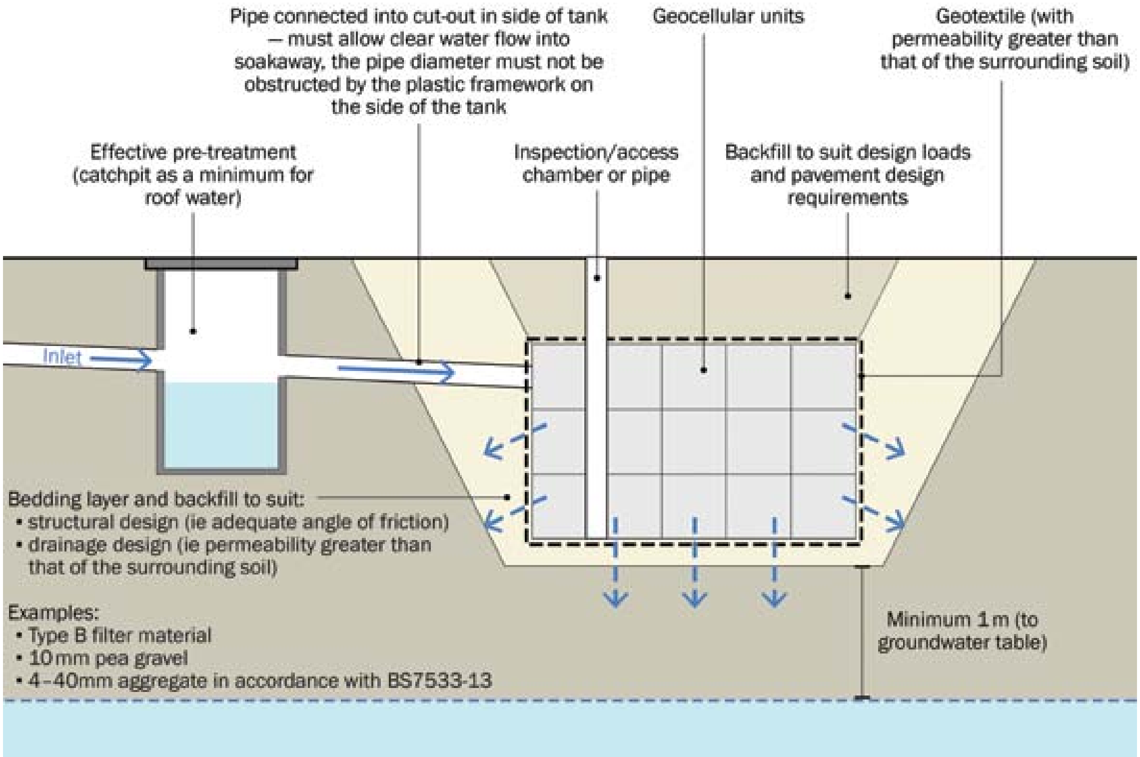

Figure 13.1 Soakaway details (including a pre-treatment system)

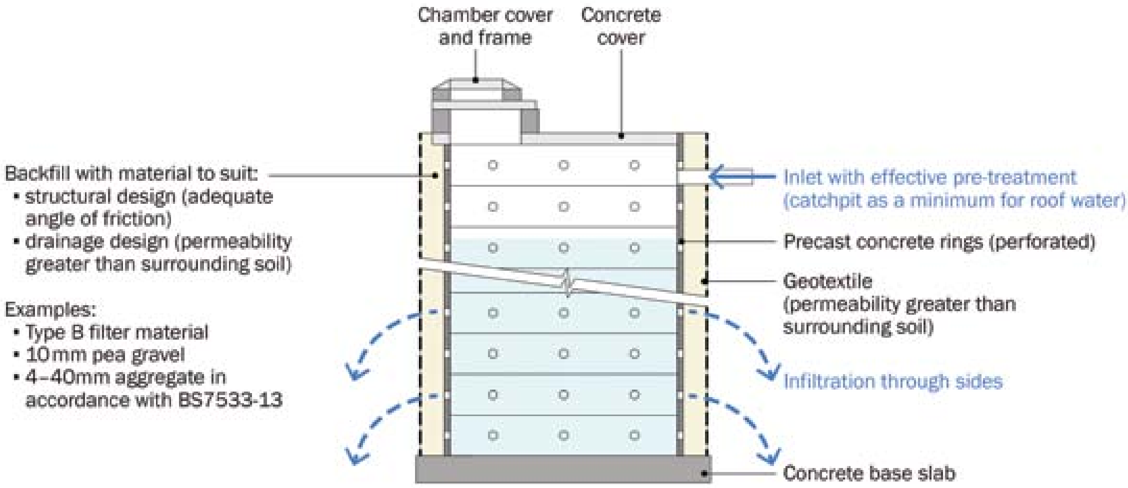

Figure 13.2 Soakaway details – concrete ring soakaway

Infiltration trenches are simply linear soakaways. The advantages of trenches over cuboid soakaways is that they can often be kept shallower and, in variable soils, can help distribute the infiltration area so that the impact of less permeable areas of soil is less pronounced. A perforated pipe can be included, if required, to distribute water along the trench. Details are shown in **Figure 13.3**.

Infiltration basins are flat-bottomed, shallow landscape depressions that store runoff (allowing pollutants to settle and filter out) before infiltration into the subsurface soils.

Schematics for infiltration basins are shown in **Figure 13.4** and **Figure 13.5**.

Infiltration blankets are large shallow systems that are typically constructed using permeable aggregate or geocellular units that act as extensive soakaway systems. Examples include below car parks where the storage layer is part of the car park pavement construction, below playgrounds or below sports pitches.

Trees are beneficial in infiltration basins as they help maintain infiltration rates of the soil. However, the design should ensure the trees selected are capable of thriving in the conditions likely to be present in the basin.

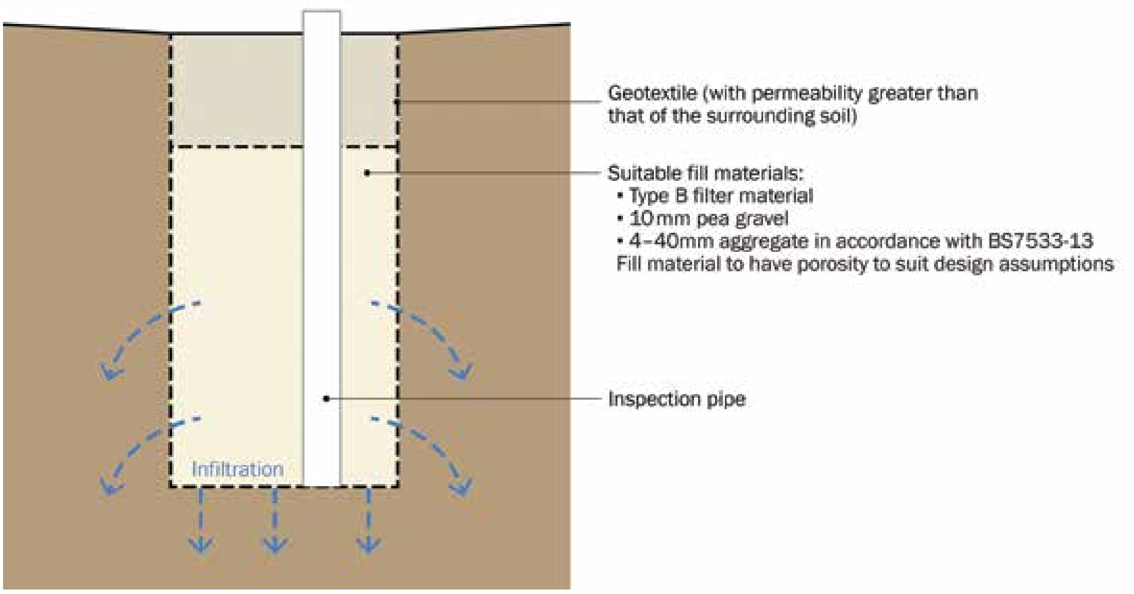

Figure 13.3 Infiltration trench

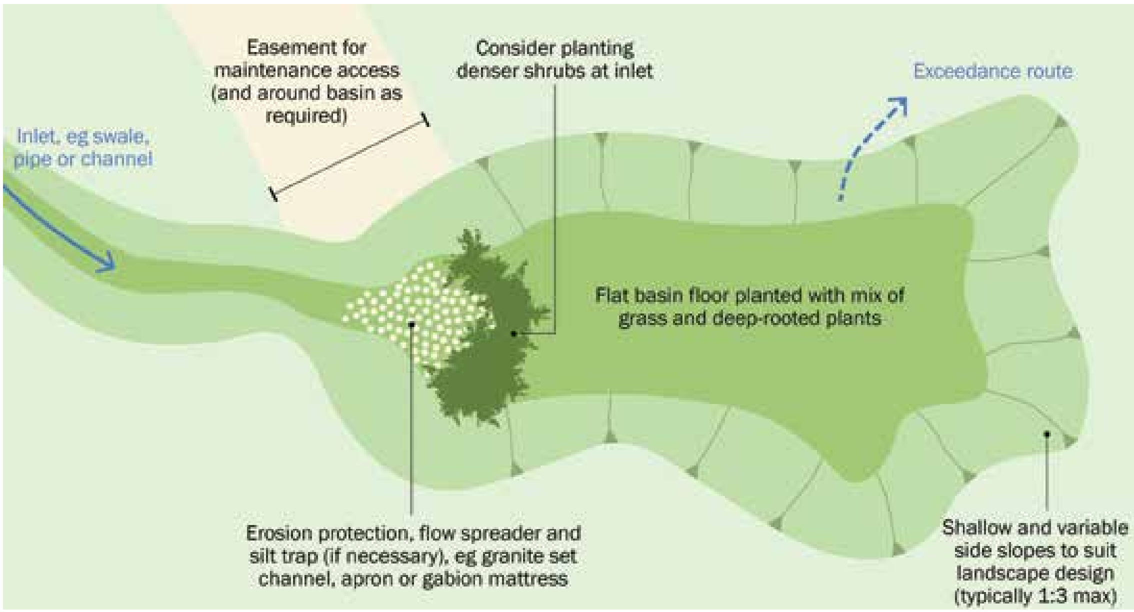

Figure 13.4 Plan view of infiltration basin

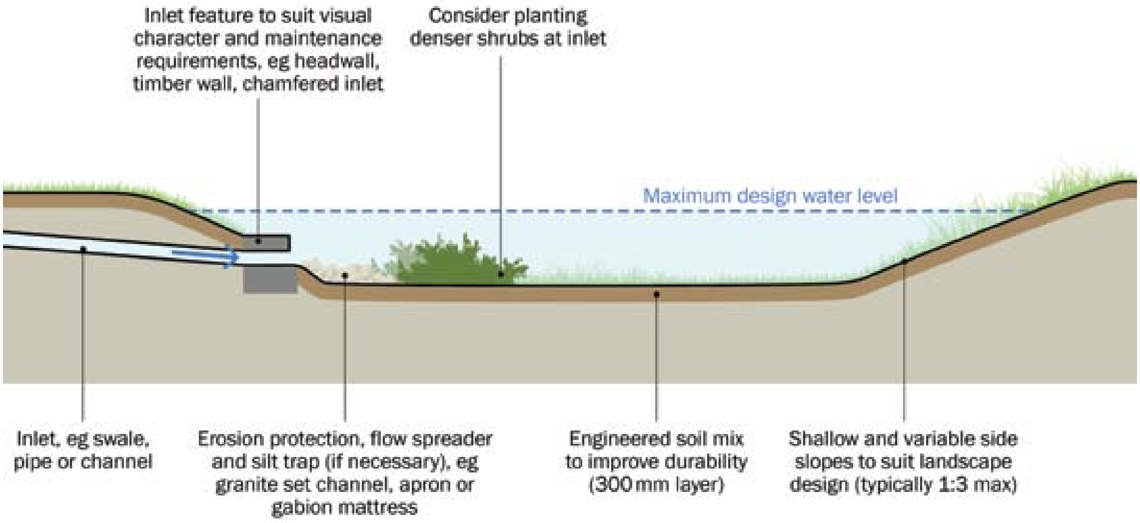

Figure 13.5 Elevation of infiltration basin

13.2 GENERAL DESIGN CONSIDERATIONS

Infiltration systems facilitate the discharge of surface water runoff to the ground and ultimately into groundwater. It is therefore crucial that any runoff is suitably clean before entering the infiltration component so that the groundwater is not put at risk of contamination.

The performance of infiltration systems is dependent on the infiltration capacity of the surrounding soils and the depth to groundwater. Effective upstream pre-treatment is required to remove sediment and silt loads to prevent long-term clogging and subsequent failure of the system. Construction best practice (**Section 13.11**) is also crucial to preventing damage to the subsoil structure (and permeability) before commissioning of the system.

Figure 13.6 Large infiltration basins, Ipswich (courtesy Graham Fairhurst)

Figure 13.7 Small infiltration basin, Cambourne (courtesy Illman Young)

A minimum distance of 1 m between the base of the infiltration system and the maximum likely groundwater level should always be adopted. This is to minimise the risk of groundwater rising into the infiltration component and reducing the available storage volume, to protect the functionality of the infiltration process by ensuring a sufficient depth of unsaturated material and to protect the groundwater from any contamination in the runoff.

The following issues should be assessed as part of the design process for infiltration systems:

- risk of ground instability, subsidence or heave due to infiltration

- risk of slope instability or solifluction due to infiltration
- risk of groundwater pollution from mobilising existing contaminants on the site
- risk of pollution from infiltrating polluted surface water runoff from the site
- risk of groundwater flooding due to infiltration
- risk of groundwater leakage into the sewers, basements, tunnels or other structures due to promoting infiltration on the site.

The evaluation and management of these risks is discussed in detail in **Chapter 25**. The design should ensure that, after construction, the residual risks will be acceptable.

The bottom of any infiltration system should be flat to provide uniform ponding and infiltration of the runoff across the surface. The tolerance on the base levels should be a maximum level difference of 10 mm in 3 m.

The side slopes of infiltration basins should normally be no steeper than 1 in 3 to allow for vegetative stabilisation, mowing, access and for public safety reasons. However, this requirement may be relaxed if a basin is very shallow (eg less than 500 mm deep). Stepped or benched slopes also offer a range of habitats that can survive fluctuating water levels and wet to dry soil conditions.

Where the temporary storage of water occurs on the surface in open features (ie infiltration basins), the depths and rate of rise of the water should be sufficiently low such that risks posed by the water body are minimised for site users and operators (taking into account the temporary nature of the storage facility which will mean that users are not accustomed to its presence). A risk assessment should be undertaken of the frequency and rate of flooding to a range of inundation depths in order that public safety is not put at risk (**Chapter 36**). Flatter slopes tend to improve the aesthetics, at the expense of extra land-take. There should always be appropriate access to the infiltration basin for maintenance activities such as grass cutting and rehabilitation of the infiltration surface. Where trees are planted in basins they should not prevent access or deter future maintenance (eg because of root protection zones).

Any inspection chambers should aim to allow maintenance from the surface without requiring man entry.

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

13.3 SELECTION AND SITING OF INFILTRATION COMPONENTS

Soakaways are best suited to the infiltration of runoff from small areas such as roofs of residential housing.

Infiltration components can often be retrofitted into existing developments, to drain small areas such as private driveways and roof drainage, providing there is sufficient offset from structures, slopes etc (**Chapter 25**). On sloping sites they may be able to be designed as a series of smaller units, rather than one large system, that are located on plateaus within the site (eg parking areas). They can also be used to manage overflows from water butts and other rainwater collection systems. The subsurface infiltration components require no net land-take. They can be built in many shapes and sizes and can often be accommodated within high-density urban developments. However, it is usually not desirable to use "open-access" infiltration basins within public open space that involves a lot of pedestrian traffic, due to the risk of deterioration of the performance of the infiltration surface due to compaction of the surface soils. Infiltration systems should not normally be used to drain landscaping or other areas with high risks of soil erosion and loadings, due to the risk of sediment blockage and clogging of the soils surrounding the component.

▶ Constraints on the use and siting of infiltration systems are discussed in **Chapter 25**.

13.4 HYDRAULIC DESIGN

13.4.1 General

Infiltration systems should be designed to manage storms up to the design standard of service required for the contributing catchment area: this could be the 1:10 or 1:30 year storm, or larger. As discharge criteria from a development site are usually based on a 1:100 year event plus an allowance for climate change, the performance of infiltration systems under such conditions needs to be known. For ease of design, and to minimise the occurrence of surface flooding within the development, this may result in the soakaways being designed to manage the 1:100 year event (plus climate change allowance).

▶ The design of infiltration components should follow the advice in **Chapter 25**.

The infiltration component should discharge from full to half-full within a reasonable time so that the risk of it not being able to manage a subsequent rainfall event is minimised. Where components are designed to manage the 1:10 year or 1:30 year event, it is usual to specify that half emptying occurs within 24 hours. If components are designed to infiltrate events greater than the 1:30 year event, designing to half empty in 24 hours can result in very large storage requirements and, with agreement from the drainage approving body, it may be appropriate to allow longer half emptying times. This decision should be based on an assessment of the performance of the system and the risk and consequences of consecutive rainfall events occurring.

▶ The procedures outlined in **Chapter 25** should be followed for the hydraulic design of infiltration components.

13.4.2 Interception design

Infiltration can play an important role in providing Interception – the capture and retention of the first 5 mm of any rainfall event, even on sites with low infiltration rates.

▶ Further guidance on Interception is provided in **Section 24.8**.

13.4.3 Peak flow control design

Infiltration reduces required attenuation storage volumes. The extent of this reduction for any return period will be dependent on the design standard of service, the volume of storage provided and the infiltration capacity of the surrounding soils.

▶ Guidance on designing for attenuation storage is provided in **Section 24.9**.

13.4.4 Volume control design

Infiltration reduces the volume of runoff. The extent of this reduction for any return period will be dependent on the design standard of service and the infiltration capacity of the surrounding soils.

13.4.5 Exceedance flow design

Infiltration components should be designed so that exceedance flows are managed effectively. An exceedance flow route or temporary storage area (eg an open space or external area) will be required for rainfall events that exceed the design capacity of the infiltration system. This can be achieved by installing an overflow pipe above the design water storage level of the infiltration systems and conveying runoff flows downstream or by effective management of volumes of water that surcharge the system.

▶ Guidance on exceedance design is provided in **Section 24.12**.

13.5 TREATMENT DESIGN

The acceptability of infiltration design, from a groundwater protection perspective, will depend on the extent of the likely runoff contamination and site and ground characteristics. An evaluation should be undertaken using the water quality risk assessment (**Section 26.7**). A depth of at least 1 m of unsaturated soils that are not clean gravels or similar with high permeabilities, and/or are not fractured deposits with rapid flow routes (preferably with some organic and clay content) are known to provide good protection to underlying groundwater.

Sedimentation tends to occur within the temporary storage area – and an allowance should always be made for this or, preferably, upstream SuDS components put in place to remove sediment before entering the component.

The deeper an infiltration system is, the greater the risk of bypassing the protective upper soil layers and decreasing the distance to the water table. This can lead to an increased risk of groundwater pollution. In this respect shallow and dispersed systems are usually best. Geotextile layers can be used within infiltration components for additional trapping of surface water runoff particulates and hydrocarbons.

▶ **Section 26.6.3** sets out the key processes that have been found to be important for groundwater protection from urban runoff.

13.6 AMENITY DESIGN

Soakaways and trenches do not usually have any inherent amenity value, but subsurface systems can promote the multi-functional use of space by allowing the overlying surface to be used for recreation or other amenity facilities.

The use of infiltration basins as amenity features needs to be balanced against the increased maintenance requirements this can cause. If the basin is purely aesthetic or biodiverse and is not used as an active or passive recreation space then there is no real increase in maintenance. If the surface is going to be used by pedestrians or used for playing informal sports, this can cause the surface to become compacted and require more frequent maintenance to maintain the infiltration capacity. Engineered soils on the surface are less likely to be adversely affected and lose infiltration capacity. Planting trees and shrubs rather than just grass, and mulching the surface layers will also help maintain the infiltration rates (although the presence of trees should not impede future maintenance – **Section 13.2**).

Basins should be designed with shallow side-slopes and benching, which will help mitigate safety risks and also provide for biodiversity and habitat creation. The form and aesthetic appearance of the facility will depend on specific site characteristics, local public concerns, and development design criteria. Fencing is generally not desirable as it may reduce the amenity benefits provided by the infiltration facility, provide a barrier to easy maintenance and provide a trap where litter and dead vegetative material could collect. Where fences are required, they should be low (toddler-proof), but facilitate movement of wildlife.

▶ More information about the need for fences around SuDS is provided on the Susdrain website: **www.susdrain.org** and in **Chapter 36**.

▶ Community engagement is discussed in **Chapter 34**

▶ Landscape and planting best practice is presented in **Chapter 29**.

13.7 BIODIVERSITY DESIGN

The ecological value of the system can be enhanced by diversifying the planting (eg including trees, woody shrubs, wildflower mixes – **Chapter 29 and Chapter 6**) or by including bioretention areas within the design.

13.8 PHYSICAL SPECIFICATIONS

For soakaways, the void should (where required) be separated from the surrounding soil using a suitable geotextile. This will support the soil around the soakaway and prevent the ingress of backfill material into the top of the soakaway during and after surface reinstatement. Characteristics of the geotextile should suit the surrounding soil particle size and permeability.

▶ Guidance on suitable geotextile specifications is given in **Section 30.5**.

Soakaways should be of sufficient strength to cater for the loads acting on them during construction and during their service life, especially where they are required to be traffic bearing. The long-term strength of materials should be carefully considered. The design and specification of geocellular soakaways should follow the guidance in **Chapter 21** regarding structural design and material specification. Precast concrete manholes should be subject to the normal structural design/ specification for concrete drainage structures.

13.8.1 Pre-treatment and inlets

Infiltration components can be susceptible to high failure rates due to clogging from sediments and therefore require effective pre-treatment to remove as much of both the suspended solids and fine silts from the runoff as possible, before they enter the system. Silt that causes clogging of infiltration systems is mainly < 6 μm diameter which is very small (Siriwardene *et al*, 2007). Designs should ideally incorporate “multiple pre-treatment”, using practices such as swales, sediment basins and filter strips in series upstream of the infiltration basin to minimise the risks. However, often this is not practical and for a small soakaway serving a roof, a small catchpit may be the only pre-treatment that can effectively be provided.

An infiltration component can be designed offline to provide volume control in larger events. This means that low flows do not enter the system (which minimises the risk of clogging, but means the component cannot deliver Interception for the contributing catchment).

Inlet channels to infiltration basins should be stabilised using appropriate erosion control, such as rip-rap, although in a well-designed system, flows will be low and erosion protection requirements should be minimal. A level spreader should also be provided at the inlet to the basin from the pre-treatment system to promote shallow sheet flow into the basin, which will maximise pollutant removal opportunities, and reduce the risks of erosion.

13.8.2 Outlets

Overflow of excess surface water runoff can be via a piped outlet or overflow or from the top of the soakaway, if considered appropriate, or a weir overflow from a basin. The overflow should not impede access to any inlet/outlet/control structure that manages more frequent flows.

13.9 MATERIALS

The materials used in infiltration components are mainly aggregate, geotextiles and engineered soils such as root zone or amended soils for simple bioretention systems.

Top soils or engineered soils used in infiltration basins should be sufficiently permeable. The minimum permeability assumed in the design should be stated, and the material should be tested after it has been placed in accordance with the method described for bioretention soils in **Chapter 18**.

▶ Further information on engineered soils and filter media is provided in **Chapters 30 and 18**.

13.10 LANDSCAPE DESIGN AND PLANTING

Infiltration basins are typically grassed structures, but some additional vegetation can enhance the appearance of the basin, stabilise side slopes and prevent erosion, and serve as wildlife habitat. Planting should be designed to suit the specific anticipated site conditions which will vary from wet to dry conditions. Native plants and vegetation may be preferable and more hardy to survive expected fluctuations in soil water levels.

Vegetation also increases the effectiveness of infiltration by slowing the flows across the basin and by maintaining or enhancing the pore space in the underlying soils via deeper rooting systems. Dense vegetation such as shrubs and mulching will also minimise the risk of clogging of surface soils (Emerson and Traver, 2008).

Any planting in an infiltration basin should be able to withstand periods of ponding and lengthy dry periods . In order to reduce maintenance requirements and increase aesthetic and biodiversity value, planting with wild flower meadow mixes can be considered (**Chapter 29**).

Infiltration components can attract the roots of plants growing in their vicinity – particularly if the plants do not have a separate supply of water. This is, to a certain extent, an advantage as plant roots take up extra water from the system and roots provide extra openings in the surrounding soil for water to infiltrate. However, too vigorous root intrusion into subsurface systems, especially from larger shrubs and trees, should be kept in check as it can fill a significant percentage of the void space required for runoff attenuation and can also cause structural damage.

Fertilising and the application of herbicides to an infiltration system should be avoided to minimise the risk of pollutants and nutrients entering the groundwater.

▶ Landscape design and planting best practice is presented in detail in **Chapter 29**.

13.11 CONSTRUCTION REQUIREMENTS

Many reported failures of infiltration systems can be attributed to poor design, inappropriate soils and careless construction. The construction process therefore needs careful planning and implementation to ensure that it does not adversely affect the infiltration performance of the systems.

Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

▶ Generic health and safety guidance is presented in **Chapter 36**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified and eliminated/reduced and/or controlled where appropriate.

13.11.1 Soakaways, trenches and blankets

Soakaways, trenches and blankets should not be used for untreated drainage from construction sites, where runoff is likely to contain silt, debris and other pollutants.

Perforated, precast concrete ring soakaways should be installed within a square pit, with side dimensions about twice the selected ring diameter. The need to oversize the soakaway pit for the purposes of constructing the ring unit chamber may be used to advantage by incorporating the total excavation volume below the discharge invert in the design storage volume (BRE, 1991). Excavations should be backfilled with a suitable permeable aggregate material such as Type B filter material, pea gravel or 4/40 aggregate in accordance with BS 7533-13:2009) – see **Chapter 20 and Chapter 30**.

Some normally highly permeable soils and soft rocks (eg chalk) can have their permeability significantly reduced by "smearing" of the surface during excavation, especially by mechanical diggers. It is recommended that the exposed surface of the soil is manually cleaned of any smearing before the geotextile and granular fill surrounding any infiltration system are installed.

13.11.2 Infiltration basins

Where possible, construction of infiltration basins should take place after the site has been stabilised, in order to minimise the risk of premature system failure due to high sediment loadings in runoff from disturbed ground. If this is not possible, then initial excavation should be carried out to within 450 mm of the basin floor, and final excavation should be delayed until after site stabilisation. It is essential that infiltration basins should not be used to manage construction runoff and trap construction sediments.

Topsoil should not be laid in basins when the ground or the topsoil is saturated. This may be a constraint to the use of infiltration basins if the construction programme is particularly tight.

All excavation and levelling should be performed by equipment with tracks that exert very light pressures, to prevent compaction of the basin floor, which may reduce infiltration capacity. Before and after construction, other vehicular movements should be prevented.

The base of the basin should be carefully prepared to an even grade with no significant undulations. The surface soils within the basin should not be smeared or compacted during construction. After final grading, the basin floor should be tilled to a depth of 150 mm to provide a well-aerated, porous surface texture.

Backfilling against inlet and outlet structures needs to be controlled to minimise settlement and erosion. The topsoils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth.

Immediately following basin construction, the base and side slopes should be stabilised with a dense coverage of water-tolerant grass.

13.12 OPERATION AND MAINTENANCE REQUIREMENTS

Infiltration systems will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. Different designs will have different operation and maintenance requirements, and this section gives some generic guidance for different system types.

13.12.1 Soakaways, trenches and blankets

The design of soakaways, infiltration trenches and blankets should include monitoring points where the water level in the system can be observed or measured. This can either be via an inspection well or inspection cover (where the attenuation storage space is a void). For larger installations the inspection access should provide a clear view of the infiltration surface (even if the storage zone is filled). For small, filled soakaways, a 50 mm perforated pipe is adequate.

The useful life and effective operation of an infiltration component is related to the frequency of maintenance and the risk of sediment being introduced into the system.

An easement should be considered where multiple properties discharge to a single soakaway, to ensure long-term access for maintenance purposes.

Table 13.1 provides guidance on the type of operational and maintenance requirements that may be appropriate for soakaways. The list of actions is not exhaustive and some actions may not always be required.

TABLE 13.1 Operation and maintenance requirements for soakaways

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Inspect for sediment and debris in pre-treatment components and floor of inspection tube or chamber and inside of concrete manhole rings	Annually
	Cleaning of gutters and any filters on downpipes	Annually (or as required based on inspections)
	Trimming any roots that may be causing blockages	Annually (or as required)
Occasional maintenance	Remove sediment and debris from pre-treatment components and floor of inspection tube or chamber and inside of concrete manhole rings	As required, based on inspections
Remedial actions	Reconstruct soakaway and/or replace or clean void fill, if performance deteriorates or failure occurs	As required
	Replacement of clogged geotextile (will require reconstruction of soakaway)	As required
Monitoring	Inspect silt traps and note rate of sediment accumulation	Monthly in the first year and then annually
	Check soakaway to ensure emptying is occurring	Annually

Maintenance will usually be carried out manually, although a suction tanker can be used for sediment/debris removal for large systems. If maintenance is not undertaken for long periods, deposits can become hard-packed and require considerable effort to remove.

Replacement of the aggregate or geocellular units will be necessary if the system becomes blocked with silt. Effective monitoring will give information on changes in infiltration rate and provide a warning of potential failure in the long term.

Roads and/or parking areas draining to infiltration components should be regularly swept to prevent silt being washed off the surface. This will minimise the need for maintenance.

Maintenance responsibility should be placed with an appropriate organisation, and maintenance schedules should be developed during the design phase.

▶ Generic health and safety guidance is presented in **Chapter 36**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified and eliminated/reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

13.12.2 Infiltration basins

Regular inspection and maintenance is important for the effective operation of infiltration basins as designed. Maintenance responsibility for an infiltration basin and its surrounding area should be placed with a responsible organisation.

Regular mowing in and around infiltration basins is only required along maintenance access routes, amenity areas (eg footpaths), across embankments and across the main storage area. The remaining areas can be managed as "meadow" or other appropriate vegetation, unless additional management is required for landscaping purposes. Grass cutting may need to accommodate specific sward mixes and specialist seed or turf supplier recommendations. As described earlier in this chapter, deep-rooting vegetation can maintain infiltration rates and minimise the need for remedial maintenance. All vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Adequate access should be provided to the infiltration basin for inspection and maintenance, including for appropriate equipment and vehicles such as mowing equipment. Table 13.2 provides guidance on the type of operational and maintenance requirements that may be appropriate for infiltration basins. The list of actions is not exhaustive and some actions may not always be required.

TABLE 13.2 Operation and maintenance requirements for infiltration basins

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter, debris and trash	Monthly
	Cut grass – for landscaped areas and access routes	Monthly (during growing season) or as required
	Cut grass – meadow grass in and around basin	Half yearly: spring (before nesting season) and autumn
	Manage other vegetation and remove nuisance plants	Monthly at start, then as required
Occasional maintenance	Reseed areas of poor vegetation growth	Annually, or as required
	Prune and trim trees and remove cuttings	As required
	Remove sediment from pre-treatment system when 50% full	As required
Remedial actions	Repair erosion or other damage by reseeding or re-turfing	As required
	Realign the rip-rap	As required
	Repair or rehabilitate inlets, outlets and overflows	As required
	Rehabilitate infiltration surface using scarifying and spiking techniques if performance deteriorates	As required
	Relevel uneven surfaces and reinstate design levels	As required
Monitoring	Inspect inlets, outlets and overflows for blockages, and clear if required	Monthly
	Inspect banksides, structures, pipework etc for evidence of physical damage	Monthly
	Inspect inlets and pre-treatment systems for silt accumulation; establish appropriate silt removal frequencies	Half yearly
	Inspect infiltration surfaces for compaction and ponding	Monthly

Accumulated sediments on the surface of infiltration systems have been shown not to pose a hazard to human health, where people are using the basin as an open space (Scott Wilson, 2010). However, Scott Wilson (2010) shows that the accumulated material exceeded the total organic carbon (TOC) criteria for hazardous waste, and the accumulated sediment would require waste pre-treatment to lower the organic content before off-site disposal (other contaminant levels were well below hazardous waste criteria). Composting or windrowing might achieve this. Excavated sediment from infiltration basins or pre-treatment component that receive runoff from residential or standard road and roof areas are generally not toxic and can therefore be safely disposed of by either land application or off-site disposal. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation, to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so.

▶ Further information on waste management is provided in **Chapter 33**.

Maintenance Plans and schedules should be developed before maintenance contracts are commissioned. Specific maintenance needs of the basin should be monitored, and maintenance schedules adjusted to suit requirements.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is presented in **Chapter 36**.

Provided preventive maintenance measures are conscientiously undertaken, the need for corrective maintenance should rarely arise.

▶ Additional detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

13.13 REFERENCES

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Statutes

BS 7533-13:2009 *Pavement constructed with clay, natural stone or concrete pavers. Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers*

Construction (Design and Management) Regulations 2015

14 PROPRIETARY TREATMENT SYSTEMS

Contents

Chapter 14 Proprietary treatment systems

This chapter provides guidance on the design of proprietary treatment systems – surface and subsurface manufactured products designed to provide treatment of water through the removal of contaminants.

14.1 GENERAL DESCRIPTION

Proprietary treatment systems are manufactured products that remove specified pollutants from surface water runoff. They are especially useful where site constraints preclude the use of other methods or where they offer specific benefits in facilitating the delivery of SuDS design criteria for a site. They are often (but not always) subsurface structures and can often be complementary to landscaped features, reducing pollutant levels in the runoff and protecting the amenity and/or biodiversity functionality of downstream SuDS components. They can be useful in reducing the maintenance requirements of downstream SuDS or in avoiding the risk of disturbance of those areas during routine silt removal operations. Historically, they have only been considered as pre-treatment devices, but they can provide a valuable function in removing pollutants from runoff and may therefore be considered as an integral part of the Management Train in some situations. Systems are available that deliver reductions in a wide range of contaminants, and increasingly sophisticated proprietary systems are being developed for use in treating runoff from developments.

Proprietary treatment systems may require more routine maintenance than other methods to ensure functionality, although it is confined to a single location and is engineering based, which may be advantageous to some owners or operators and can reduce overall maintenance costs (HA, 2014). Their treatment performance may also be more dependent on routine inspection or maintenance than other types of SuDS, although this will be system and design specific. Where large volumes of sediment may accumulate in the device, suction equipment is usually needed to remove it, and appropriate access will have to be provided. Where there is no indication that maintenance is required (such as an alarm or visible surface ponding when full) then maintenance regimes need to be robust, so that activities will be triggered despite the lack of system visibility on the surface.

When designed in accordance with this manual, SuDS components, such as pervious pavements and swales, generally deliver treatment alongside hydraulic control and amenity and biodiversity benefits. With proprietary treatment systems, Interception and attenuation will usually need to be delivered separately using either surface or subsurface storage, and alternative means of delivering amenity and biodiversity criteria will also need to be considered.

14.2 GENERAL DESIGN CONSIDERATIONS

There are various types of treatment system available. These have been split into different groups based on the main processes that occur within the systems, following an adaptation of the approach described by Leisenring *et al* (2012). The main treatment processes (or process groups) that can occur in the most commonly available proprietary systems are:

- biological filtration

- filtration
- filtration and adsorption
- physical removal of sediment
- physical removal of floatables
- wetting and drying to promote degradation.

The various types of system, together with the main treatment processes, are set out in **Table 14.1**.

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

TABLE 14.1 Proprietary systems classified on basis of main treatment process

Proprietary systems	Description	Treatment processes	Leisenring (2012) classification
Proprietary bioretention systems in concrete (or other material) structures	Filtration devices that use soils (or other filter media) and which support plants or bacterial biofilms	Filtration, adsorption, bioremediation	Biological filtration
Treatment channels	Channels that are designed to collect and treat water rather than convey it along the channel; can include proprietary filter media within the channel; can include weir and baffles at intervals to trap oils and floatables	Physical removal of sediment, oils and floatables; wetting and drying to promote degradation	Does not include test results for this type of system (note that there are examples in Europe that are certified by DiBT in Germany)
Hydrodynamic or vortex separators	Structures that use gravity and centrifugal force to separate out and collect medium-sized (63 to 250 μm) sediments and other litter or debris; smaller particles may be able to be removed by varying the flow rate into the system	Physical removal of sediment by gravity	Manufactured device – physical
Proprietary filtration systems	Devices that filter water by passing it through various filter media; they are constructed below ground in chambers and do not support vegetation	Filtration and adsorption	Filtration
Oil separators	Structures designed to separate gross amounts of oil and large size (> 250 μm) suspended solids from water; they do this by allowing light non-aqueous phase liquids (LNAPL) to float and large sediment particles to sink; many also have baffles, coalescers and oil skimmers to speed-up or enhance performance	Physical removal of floatables, physical removal of sediment by gravity	Oil/grit separators and baffle boxes
Multi-process	Systems that include multiple treatment processes in series	Various	Multi-process

14.2.1 Proprietary bioretention systems in concrete (or other material) structures

These are effectively prefabricated, bioretention systems or tree pits and should behave and be designed as such (**Chapter 18 and Chapter 19**). They may include proprietary filter media that should be demonstrated as meeting the criteria set by the Facility for Advanced Water Biofiltration (FAWB) (**Chapter 18**) or provide equivalent or improved hydraulic and water quality performance. The proprietary structure can provide protection for tree roots from compaction if required, but a sufficient volume of soil should be provided for healthy tree growth (**Chapter 19**).

14.2.2 Treatment channels

Treatment channels are surface channel drainage systems that are modified to prevent or reduce water flow along them with baffles and/or weirs at intervals or, if a filter material is included, via holes in the base. Each section of channel may have its own outlet. The channels are a source control method and are different from standard channels that simply convey water to other features. They act as collectors of water from adjacent impermeable surfaces and then store it before allowing the water to discharge downstream to the next part of the system. The key to their successful use is that they should drain relatively small areas of hard surface to each metre of channel so that runoff volumes and pollution loads on any section of the channel are low (usually less than 25 m^2 per metre length of channel for separation channels and up to 100 m^2 per metre length for filtration channels, although it will be specific to each site and to the dimensions of a particular unit). The low flows also minimise emulsification of oils and help in their removal.

The two main types of treatment channel are differentiated by the process within them:

- With separation, particulate pollutants are trapped by gravity separation (settling) and floatables such as oils by physical separation using weir and baffle plates. They will not remove dissolved contaminants. A limited amount of biodegradation of hydrocarbons occurs; this occurs as the accumulated silt alternately wets and dries, especially in summer.
- With filtration, some channels are filled with a filter medium to provide filtration (which may remove dissolved contaminants – **Figure 14.4**). These may remove dissolved contaminants. Biodegradation occurs within the filter medium, due to wetting and drying through all seasons, and the effectiveness depends on the specific properties of the medium. The filter medium can be located in discrete compartments formed by baffles in the channel to promote vertical water flow through the medium.

The channels require routine maintenance to remove accumulated silt build-up, The frequency is, however, dependent on specific silt load and the dimensions of the channel; it can vary from 6 months to 10 years. They are normally designed so that if silt does build up, it blocks the outlet and water overflows to adjacent sections of channel over the surface. Thus if maintenance is not carried out the effects become visible on the surface.

A schematic of one particular type of treatment channel is shown in **Figure 14.1** and a photo of the installation of a similar product is shown in **Figure 14.2**. This concept can also be incorporated into kerb drains. Simple treatment channels are shown in **Figure 14.3**.

Treatment within open channels benefits from sediment ultraviolet light exposure (if the cover lets in sufficient light) and cyclical sediment wetting and drying, which aid in breaking down pollutants. Dry silts and sediments are also considerably simpler to remove, as de-watering is not then required.

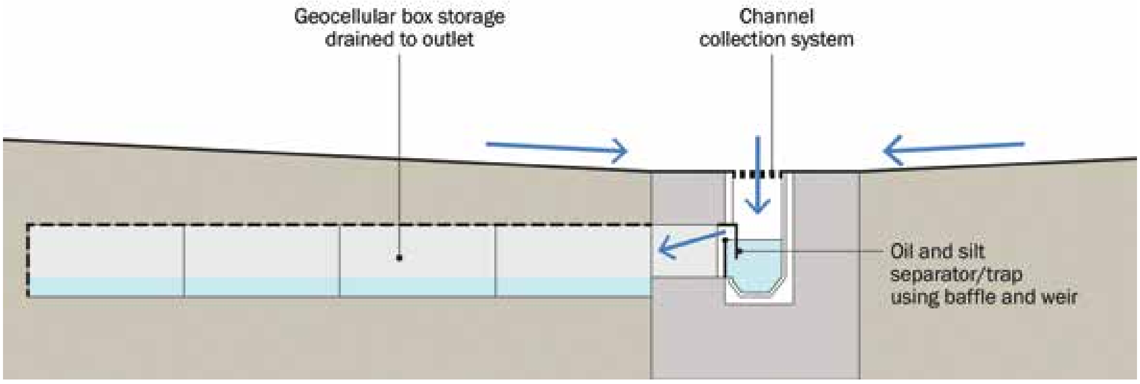

Figure 14.1 Schematic of a commonly used treatment channel

Figure 14.2 Treatment channel installations showing discrete 1 m sections (courtesy Permavoid Limited)

Outflow is via infiltration to the ground or a filter drain below the channel (courtesy Hauraton UK Limited)

Outflow is via a perforated pipe in the filter media (courtesy Stormwater Management and Funke Kunststoffe GmbH)

Figure 14.3 Treatment channels with filter medium inserts

14.2.3 Hydrodynamic or vortex separators

Hydrodynamic or vortex separators are vault structures with a gravity/centrifugal settling or separation unit to remove medium and large size sediments. They should not be confused with vortex flow controls (**Chapter 28**). The water moves in a centrifugal (circular) manner from the inlet to the outlet, thus facilitating the sediment removal process within a small space. The primary removal mechanism is sedimentation due to the increased residence time of water compared to a simple catchpit because the helical path from entrance to outlet is much longer than the straight distance between them (**Figure 14.4**).

The circular movement also creates a vertical vortex (like a vertical whirlpool) in which the centrifugal forces created by the circular motion cause suspended particles to move to the centre of the device. Velocities here are lower and they settle down to a sump at the bottom. They can either be designed to accommodate the full flow to be conveyed downstream, or can be installed downstream of a bypass structure, so that high flows are routed around the device. Typical layouts are shown in **Figures 14.5 and 14.6**.

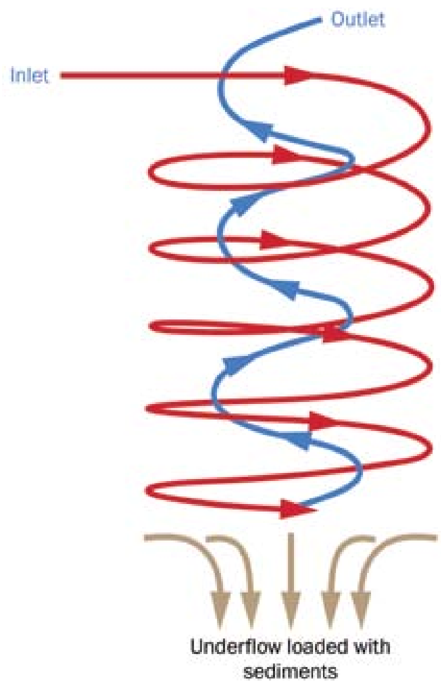

Figure 14.4 Simplified flow pattern in a vortex separator (from NJCAT, 2005)

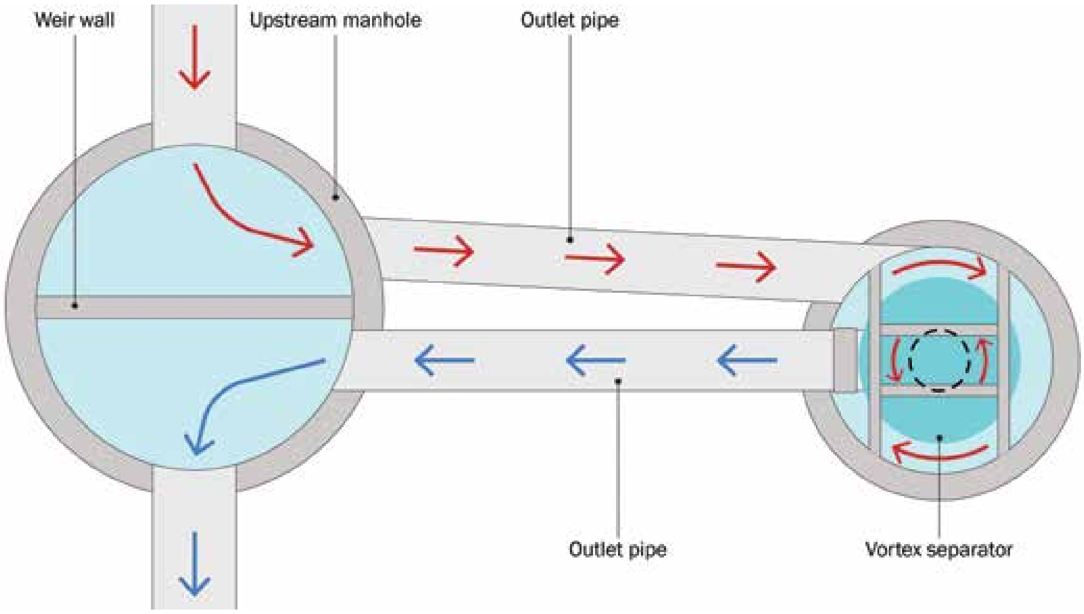

Figure 14.5 Hydrodynamic separator with a separate external bypass (courtesy Hydro International)

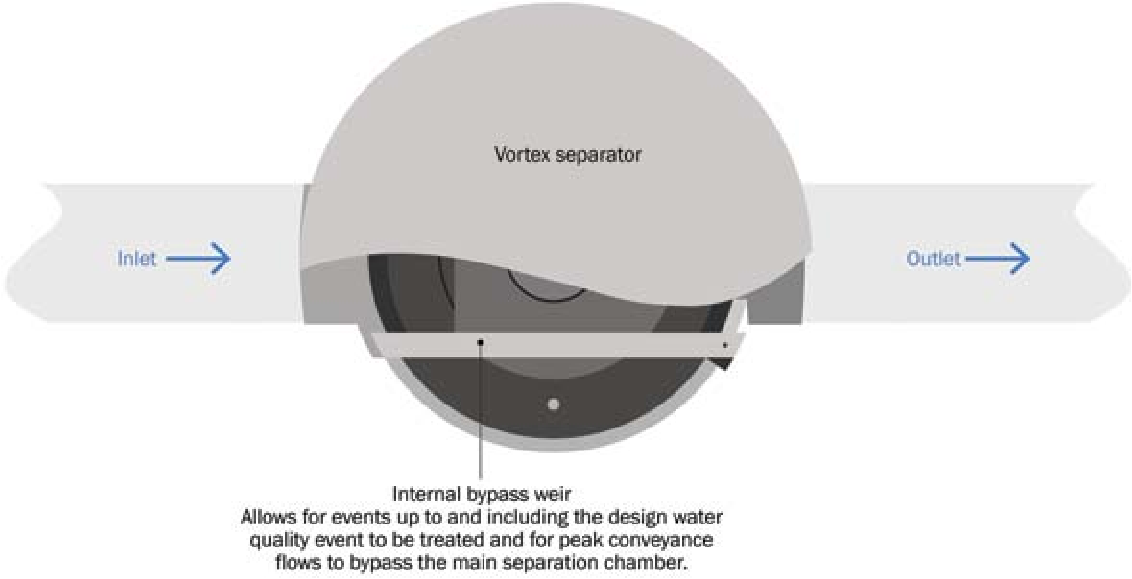

Figure 14.6 Hydrodynamic separator with an internal (or integral) bypass (courtesy Hydro International)

Vortex separators are most effective where the materials to be removed from runoff are able to be settled, or floatables (which can be captured). They cannot remove small diameter solids (eg < 115 μm) with poor settleability, emulsions or dissolved pollutants. Note that the removal of settleable particles is dependent on residence time and therefore flow rate. Reducing flow rates into a device increases residence time and enables removal of particles with longer settling times.

If the facility does not have a bypass for events exceeding the water quality event, it should be sized to accommodate the peak flow of the maximum design event likely to be conveyed by the surface water management system. A check should also be made that the stated removal performance is applicable for events up to and including the design water quality event, as described in **Section 4.3.2** (rather than the design conveyance event for which pollutant removal will be less of a concern). Where a bypass is provided, the facility should be sized to accommodate all events up to and including the design water quality event.

There is a wide variety of proprietary vortex separator units which vary considerably with respect to geometry and the inclusion of radial baffles and internal circular chambers. As well as the standard units, some manufacturers offer supplementary features to reduce the velocity of the flow entering the system (thus increasing the efficiency by allowing more sediment to settle out), reducing turbulence or improving performance by the inclusion of static separator screens. The units are generally prefabricated as a range of standard units, but they can often be customised for a specific site if required.

The various types of vortex separator have been placed into subcategories by the USEPA (1999). These are as follows:

Simple vortex separators – these rely on a rotating flow field induced in the device to cause enhanced gravitational settlement of solids in runoff. The rotating flow results in a longer flow path and extended residence time for particles, and thus settlement of a greater size range of particles occurs.

Advanced vortex separators – these operate in a similar manner to simple vortex separators but they have internal components to control and enhance separation performance and provide isolated zones for captured sediments to prevent resuspension and washout under peak flow conditions (see an example schematic in **Figure 14.7**).

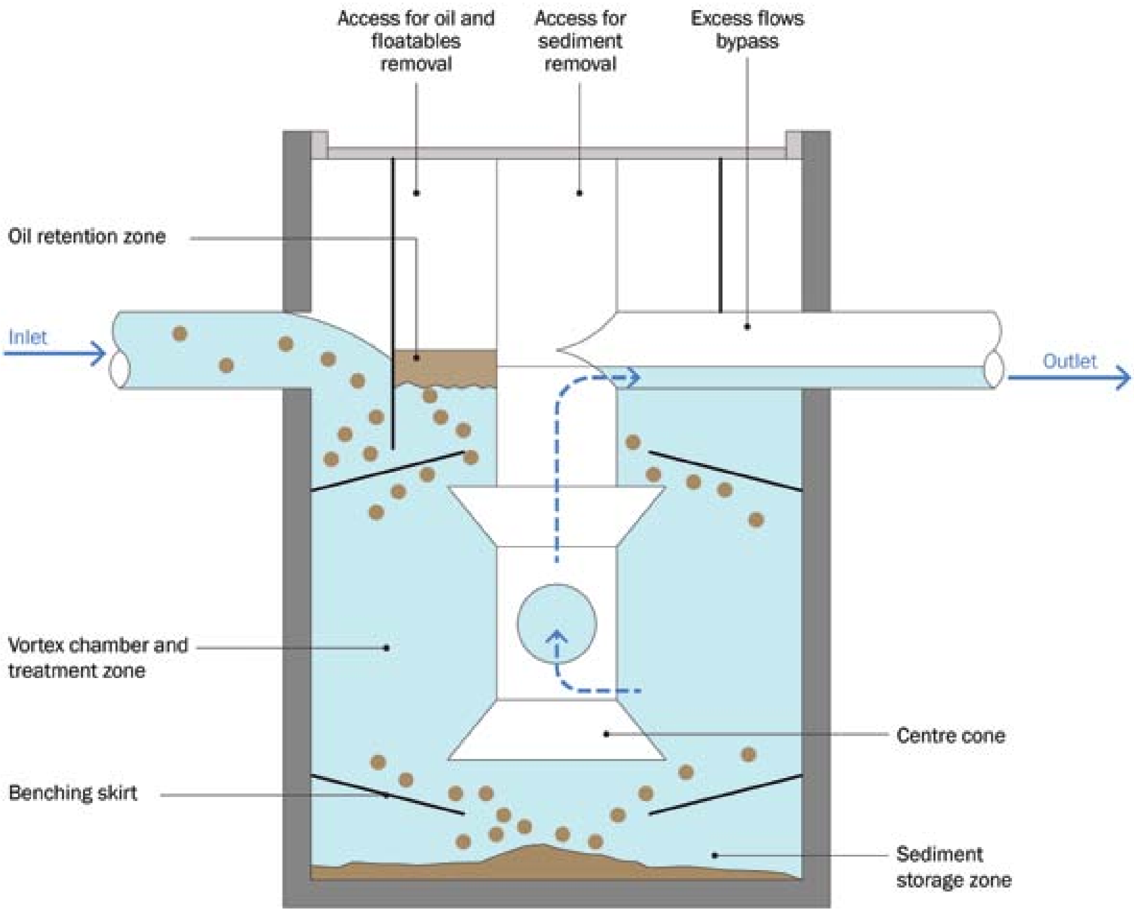

Figure 14.7 Typical schematic of a hydrodynamic separator unit (courtesy Hydro International)

Hydrodynamic separators need routine maintenance to ensure continuing proper operation and sediment removal efficiencies. They are usually underground, so malfunctioning is not easy to detect and therefore often ignored (although they can have alarms fitted to warn when cleaning is necessary). This can cause poor outflow water quality due to resuspension of solids and anaerobic conditions developing within the device. However, once the sediment accumulation has been observed over the first year of operation the maintenance intervals can be more accurately predicted and included in site Maintenance Plans.

Hydrodynamic systems such as these typically consist of a standard concrete manhole with internal components made from either polypropylene or stainless steel. The service life will depend on a number of factors including the operational life of the internal components and the long-term structural integrity of the system and its chamber. With routine maintenance, they should typically function effectively for a period in excess of 40 years.

▶ Further information on vortex separators is provided in HA (2014).

14.2.4 Proprietary filtration systems

Filter systems work by routing surface water runoff through the filtering or sorbing medium, which traps particulates and/or soluble pollutants. They are particularly useful for removing small particles that may bypass any single gravitational process, and some more advanced filters will remove dissolved constituents that pass through simple mechanical filtration. Filter-based SuDS often combine simple filtration with molecular level chemical processes to efficiently capture contaminants.

Proprietary filtration systems for treating surface water runoff have evolved from conventional sand filter systems and are used more widely in the USA than in the UK. During the early stages of development, a leaf compost medium was used in fixed beds, replacing the original sand content. More recently developed systems usually hold filter media in cartridges and a wide array of filter media are available including leaf compost, pleated fabric, cellulose, activated charcoal, perlite, amended sand and perlite and zeolite. Filter materials are continuously being developed to address common issues such as re-entrainment due to salt mobilisation.

Consideration should be given to the physical design of such products. Online systems should be designed to treat the water quality event and be able to accommodate the peak conveyance flows. Offline systems should be sized to treat the water quality event. Sediment loading will tend to clog filters, so they should be designed to minimise this and cleaning and replacement should be practicable. The frequency of filter replacement will vary depending on the site and filter system used. In some cases, yearly replacement of filters has proved necessary. Furthermore, the filter medium should be tested for clogging (colmatation) characteristics. Peak loads go hand in hand with shorter contact times, and it is important that peak flow performance is understood as well as the contrasting low flow regime.

Filtration systems can be purchased as prefabricated standard units or custom-made to suit site conditions. Some of the components on the market combine vortex separation and on-line filtration in one system (**Figure 14.9**). All events are treated by the vortex separator, with the filter then treating all flows up to the water quality treatment event. Excess flow will bypass the filter medium beneath the filter bed, thus avoiding the need for external diversion chambers.

The filters are usually contained in concrete manhole rings or bespoke chambers. Filters may need vertical space to allow gravity to pass the flow through the medium. In such cases this influences the invert levels of the incoming and outgoing pipes. It is also important to consider backflow events when the outlet could be submerged or surcharged.

Filters need routine maintenance to ensure continuing proper operation. They are usually hidden beneath the ground, and malfunctioning is not easy to detect and therefore is often ignored. This can cause poor outflow water quality due to resuspension of solids or clogging, resulting in flows bypassing filters within the device. A major consideration is the availability of bespoke filter cartridges in the future if the manufacturer ceases trading or discontinues production.

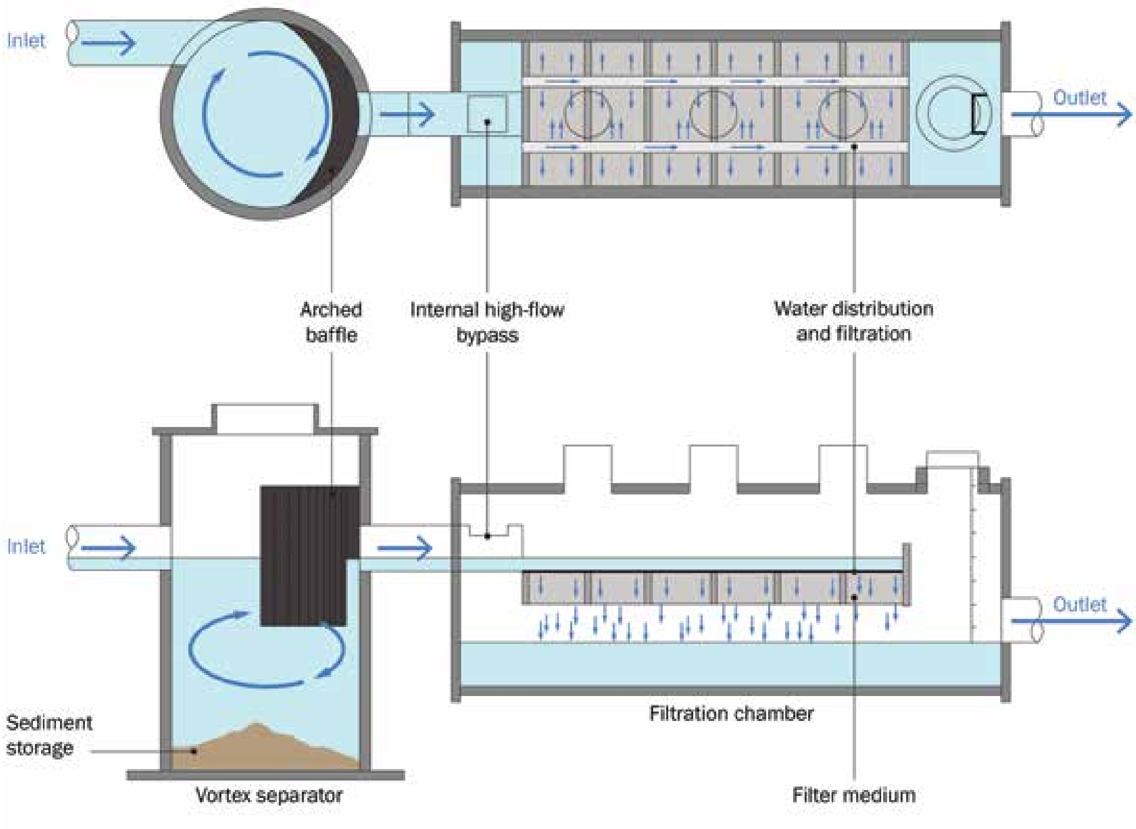

Figure 14.8 Schematic of a vortex-enhanced sedimentation and media filtration system

14.2.5 Oil separators

Oil/water (or gravity) separators are widely used to prevent hazardous chemical and petroleum products from entering watercourses and public sewers. They should be installed close to the potential pollution source to minimise emulsification of oils and their coating of sediments. An example of a large oil/water separator under construction is shown in **Figure 14.9**.

Separator designs are almost all based on the principle of separation by flotation, residence time and particle density and size. Globules of lower density oil or grease (LNAPLs) in clean non-turbulent water will rise due to buoyancy. The extent of particle displacement depends on the residence time. Once on the surface, they can be effectively removed by skimming, pumping etc. Gravity separators cannot be used for the removal of dissolved or emulsified oils and pollutants, such as coolants, soluble lubricants, glycols and alcohols. Since resuspension of accumulated sediments is possible during heavy storm events, separator units are typically installed offline.

Gravity separators are available as prefabricated proprietary systems, but can also be built *in situ*. The facilities should comply with BS EN 858-1:2002. Guidance is also provided in Pollution Prevention Guidelines (PPG) 3 (EA/SEPA/EHSNI, 2006). The design criteria and specifications of a proprietary gravity separator unit should always be obtained from the manufacturer.

Compared to other SuDS, these facilities rely heavily on frequent routine maintenance to prevent pollution. If this does not occur, experience shows that they quickly start to convey pollution downstream. They are usually hidden beneath the ground, and pollution that is trapped in the system is not obvious and can contribute to the deterioration of downstream water quality if allowed to accumulate. This can be mitigated to some extent by the incorporation of automatic monitors, as required by the British Standard. However, the monitors do need to be linked to a location that is clearly visible by the site management team when it alarms. The polluted runoff may also become visible in the outfall to any surface features, which will give warning that maintenance is required.

Figure 14.9 Large oil separator under construction (courtesy ACO Limited)

There are two classes of systems. A Class 1 device means the resultant effluent should contain 5 mg/l hydrocarbon content or less under standard test conditions. Class 2 devices can contain up to 100 mg/l in their discharge and are appropriate where drainage is to a foul sewer. It should be noted that these are the test requirements; in practice the effluent may not meet these standards.

Within the two classes are two types based on incoming and outgoing flow control – full retention or bypass separators. A full retention unit is designed to treat all the incoming flows to the designated class. Bypass separators are limited in treating events up to a certain flow rate, after which flows are bypassed to the receiving drainage system.

▶ Guidance on the selection of oil separators is provided in PPG 3 (EA/SEPA/EHSNI, 2006).

Oil/water separators used in the drainage industry usually take the form of a chamber or number of chambers situated within a drainage system to collect hydrocarbon pollutants. The majority of *in situ* separators are formed in concrete. Prefabricated units are generally manufactured in glass-reinforced plastic, polyethylene, steel or concrete. Systems should be watertight and designed to prevent flotation where there is a risk of high groundwater levels.

Oil separators are designed for a specific flow rate, unlike most other structural controls, which are sized on the basis of capturing and treating a specific volume. The separation chamber should provide for three separate storage volumes:

- a volume for separated oil storage at the top of the chamber
- a volume for settleable solids accumulation at the bottom of the chamber
- a volume required to give adequate on-line detention time for separation of oil and sediment from the surface water runoff

▶ A basic approach to sizing separators is set out in PPG 3 (EA/SEPA/EHSNI, 2006).

Figures 14.10 and 14.11 show schematics of prefabricated single and multi-chamber separators.

A typical gravity separator unit may be enhanced with a pre-treatment vortex separation chamber, oil draw-off devices that continuously remove the accumulated light liquids, and flow control valves regulating the flow rate into the unit. Plate separators provide alternative options designed to induce laminar flow conditions through a series of parallel plates. They are generally designed to treat low flow rates only, but can achieve high pollutant removal efficiencies.

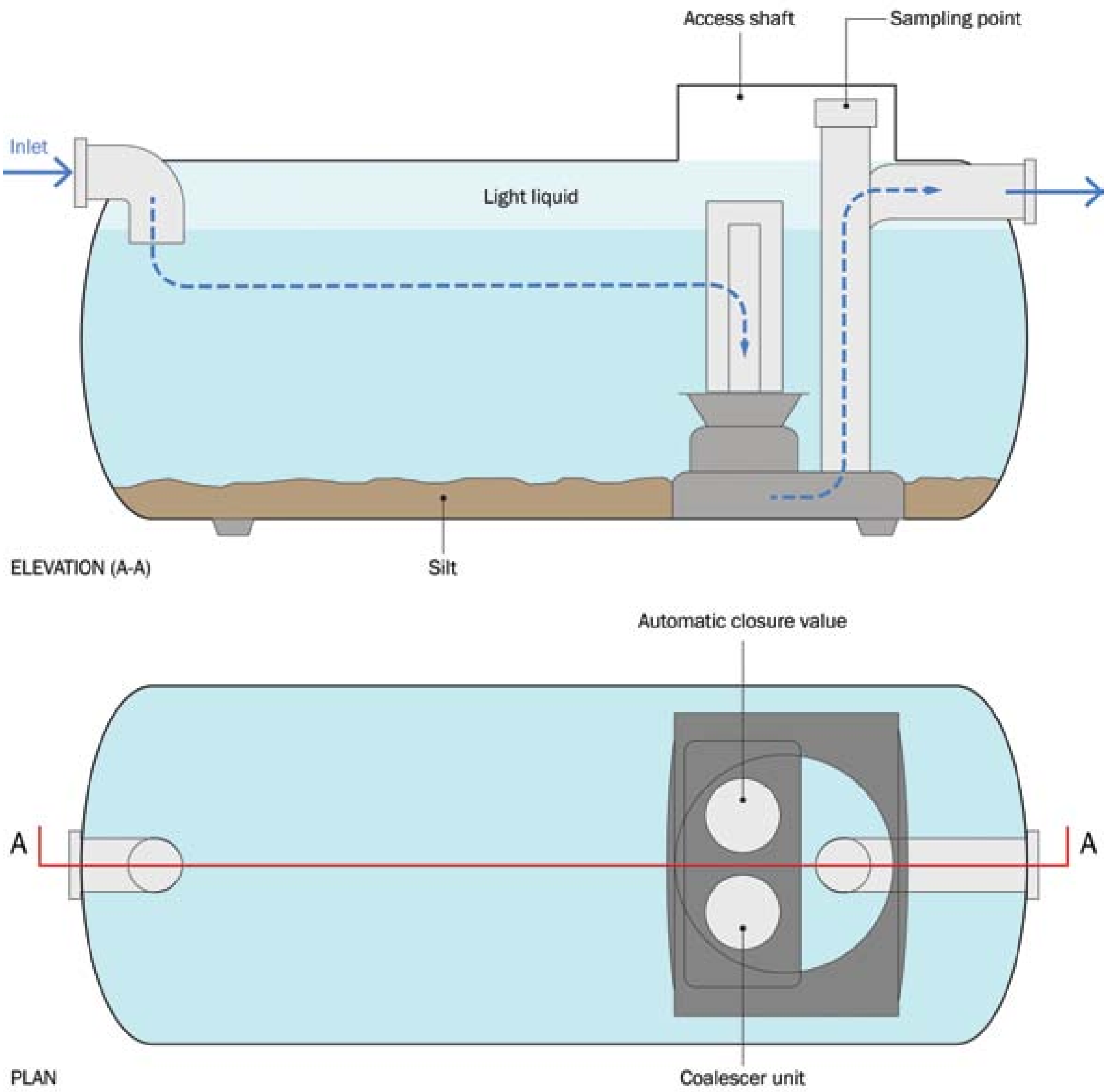

Figure 14.10 Outline diagram of a prefabricated, single chamber, full retention, Class 1 separator

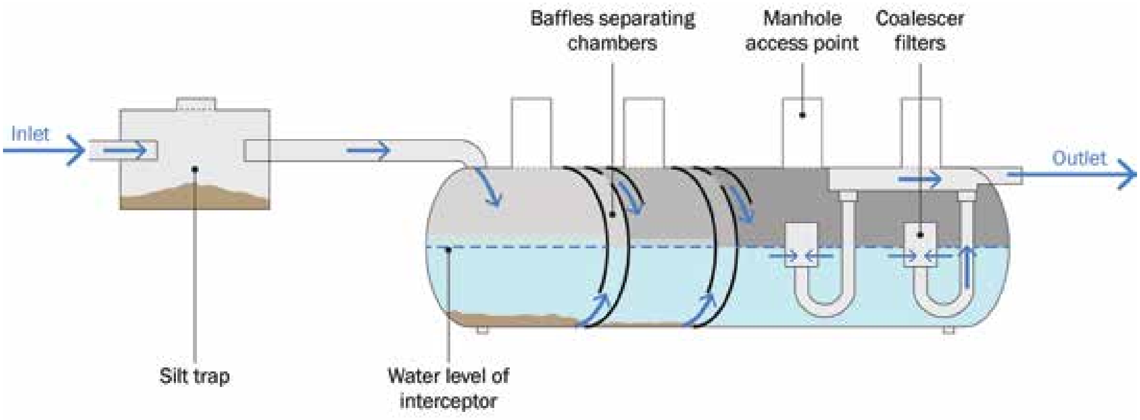

Figure 14.11 Outline diagram of a prefabricated, multi-chamber, full retention, Class 1 separator

14.2.6 Multi-process systems

Many proprietary products will use a combination of processes to effect treatment, often within one element or unit. In the example shown in **Figure 14.12**, larger particulates settle or float while smaller particles, emulsions and dissolved constituents are captured by the filter medium.

Some systems provide a combination of different treatment processes within a single proprietary system. These types of system will be able to remove a wider range of pollutants than a device based on one single process.

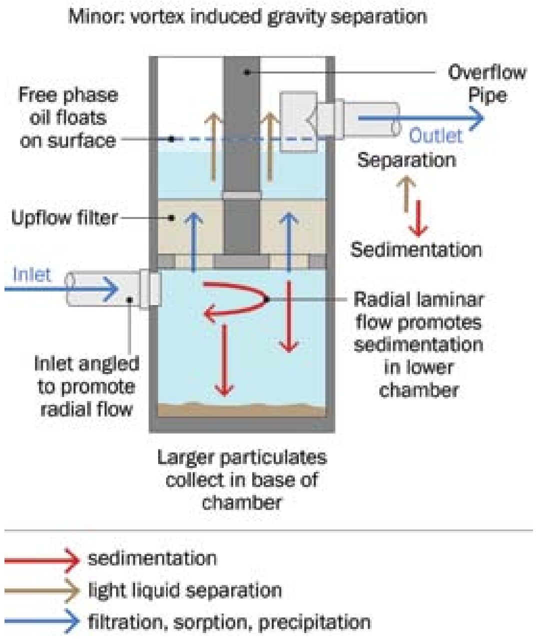

Figure 14.12 Multi-process system

14.3 SELECTION AND SITING OF PROPRIETARY TREATMENT SYSTEMS

The choice of proprietary treatment system will be dependent on the following aspects of the SuDS design:

- **Space** – Where an above-ground SuDS Management Train can be delivered within the available landscape space and meet any other constraints (including client requirements), using below-ground proprietary systems may add to the capital and maintenance costs. Where sites are constrained or surface systems are precluded for other reasons (eg when retrofitting existing sites), the use of subsurface proprietary systems tends to become more cost effective.
- **Access** to the device/system is important for maintenance and management and should play a role in siting.
- **Type of pollutants to be removed** – Proprietary systems should be selected with pollutant removal capabilities that match the range and concentrations of pollutants that may be present in runoff from the site.
- **Range of flow events for which contaminant removal is desired** – Proprietary systems should be selected with specified pollutant removal efficiencies for events up to and including the design water quality event (**Section 4.3.2**) for the catchment area draining to the system (for both online and offline systems). Online systems should have sufficient capacity to manage the maximum design flow through the system without significant re-entrainment of pollution, and offline systems should manage this flow via a suitably sized bypass.

The systems should be designed to be as shallow as possible but can often be located under roads, car parks and open space. There are instances where the use of proprietary SuDS can increase the length of time between maintenance for other components, and as a result can lower overall maintenance liability.

14.4 HYDRAULIC DESIGN

14.4.1 General

Proprietary treatment systems should be designed so that the runoff rates and volumes to them are within the stated performance envelope for the particular system, throughout its intended service life. Care is required to ensure that flows from larger rainfall events can be managed by the units without significant resuspension of sediment or other pollutants. If this cannot be guaranteed then larger flows will need to be diverted around the systems.

14.4.2 Interception design

Proprietary treatment systems do not generally provide Interception (except for proprietary bioretention systems, if designed to drain small catchment areas).

14.4.3 Peak flow control design

Proprietary treatment systems do not generally provide peak flow control.

14.4.4 Volume control design

Proprietary treatment systems do not generally provide volume control.

14.4.5 Exceedance flow design

Proprietary treatment systems should be designed so that runoff rates and volumes that exceed the stated system performance envelope are routed to the next part of the drainage system along safe exceedance flow paths. Because these systems can store large concentrated volumes of free pollutants, it may be necessary to consider their operation in flood situations where surcharging etc can backwash pollutants out of a system.

▶ Guidance on exceedance design is provided in **Section 24.12**.

14.5 TREATMENT DESIGN

Proprietary treatment systems include a wide variety of designs and component types that can provide a range of treatment processes as described in **Section 14.2** (biological filtration, filtration, adsorption, physical removal of sediment by settling, removal of floatables or a combination of processes). Wetting and drying of sediment also promotes degradation of organic pollutants. The ability of a specific device to remove particular pollutants from surface water runoff is related to the treatment processes it supports and the nature of pollutants as well as pollutant loading rates.

The size and density of sediment will influence sedimentation and filtration. Large diameter sand particles are much easier to capture than suspended clay colloidal particles and extremely small colloidal particles may be subject to Brownian movement and remain suspended indefinitely (although it is worth remembering that SuDS are not trying to remove all pollution from runoff, so in practice this may not be an issue). The smaller the particle size the more likely it is that some form of filtration may be required to remove it. It is preferable to avoid oils emulsifying in the first place by avoiding large flows of turbulent water (ie use proprietary systems that are source control systems). If oils do become emulsified they will require filtration to remove them. Dissolved pollutants (zinc and copper are commonly in dissolved form in runoff) may require adsorptive filtration or precipitation to be effectively removed.

Therefore, in a similar manner to any SuDS component, these systems should be part of an overall Management Train (**Chapter 4**). Their contribution to meeting the objectives of the required treatment strategy at any particular site should be demonstrated with respect to the type of contaminants that are managed by the system and the likely performance level. Justification should be provided regarding the level of mitigation assumed for any product (**Chapter 26, Tables 26.3 and 26.4**). Evidence of the potential efficiency of components that use different process types is presented in **Chapter 26, Annex 3**. However, these should not be assumed to be delivered by a proposed component without appropriate supporting evidence. Also, meeting existing standards is not adequate justification in itself, without evaluating the standards requirements in the light of the treatment methodology set out in this manual.

Manufacturers should provide clear guidance on how to design their specific system to meet the stated performance envelope. They should state the pollution removal performance for each contaminant at a range of flow rates, and these should be used in determining catchment areas for the upstream drainage system.

The treatment performance of proprietary systems in the field tends to be as variable as more traditional SuDS such as swales or basins and can be dependent on a wide range of factors including: the characteristics of the contaminants present in the runoff, the treatment process type(s) employed by the system, the influent concentrations, the inflow rate and the maintenance history. There may also be an observed decline in performance of some systems during cold weather (those that are dependent largely on particle settling time because the changes in water temperature affect the settling velocity of particles). Some manufacturers make claims of guaranteed performance, but such claims should be treated with caution (as they should be from designers of non-proprietary systems) unless supported by evidence from independent third parties (the evidence is that they are just as variable as other SuDS when placed in real situations outside the laboratory).

Because all systems are different, it is important that evidence is provided to support any performance claims. In the UK, there are currently no standardised testing methods or reporting protocols for proprietary surface water runoff treatment products. However, it is recommended that all testing is undertaken by organisations that are independent of the manufacturer in order to ensure that any performance claims are supported by robust evidence using appropriate test methods that may include field trials to demonstrate real-world performance. If not, the testing and results should be peer-reviewed by an independent third party. There are internationally available standard tests that can be completed (eg State of Washington, 2011, State of New Jersey, 2013, DIBt, 2011, and Dierkes *et al*, 2013) to allow the publication of performance data.

DIBt (2011) is widely used in Europe, and there are treatment channels and filter systems that meet the requirements of this standard. The standards used in the Netherlands and produced by Kiwa are very similar to the DIBt standard.

There is also a UK test protocol under preparation at the time of writing by British Water, and this will detail a test procedure that UK manufacturers can undertake, with independent witnessing.

Any performance testing should take account of the following recommendations:

- Testing should be undertaken over a representative range of rainfall events that are applicable to the design and operation of the system. The main interest is the performance for events up to a 1:1 year and the risk of resuspension during larger events due to turbulence if the system is designed to be on line. Laboratory test data should cover design flows into the system for a range of representative rainfall events to at least a 1:1 year event. Greater flow rates than the design event for water quality should also be tested to assess resuspension in on-line systems.
- Sediment loads and the particle size distribution is very important and has a significant influence on the estimated performance. Tests should use particle sizes that are representative of the range of sizes likely to be present in sediment in runoff – with particular importance given to those < 63 μm; Particle size ranges are especially important when testing the effectiveness of hydrodynamic separators, and the larger the average particle size used for evaluation, the higher the treatment efficiency. The specific gravity and grading of the particles used in any assessment should be clearly stated and compared with the site-specific design requirements.

- Measurements of particle size distribution should be included in any sampling and analysis programme, to assess the removal efficiency of total suspended solids, as well as that of other contaminants associated with various particle size fractions. There is a higher concentration of pollutants in the smaller particle sizes (< 63 µm), but when examining the mass distribution of the pollutants, particle sizes greater than 63 µm may, in some instances, be of equal concern.
- If field sampling is carried out, the effects of supernatant displacement and active-particle removal by the system (ie hydrostatic versus hydrodynamic separation) should be differentiated. This requires flow-proportional sampling throughout each storm event.
- If field testing is carried out, account should be taken of antecedent conditions, bypass flows and resuspension when estimating the performance of the system.
- A sufficient number of storms should be sampled if field tests are undertaken, not only to obtain statistically significant data, but also to include as wide a range as possible of operating conditions to which the device will be subject. In the USA, there is a phased approach to certification of proprietary systems whereby limited use is allowed based on laboratory tests to allow field data to be collected. This avoids stifling innovation.
- Treatment performance should be analysed by considering the total load of pollution which is the preferable method for accuracy and quality control.
- Storms should be sampled sequentially, to allow for a mass-balance evaluation.
- Testing and monitoring should be relevant to the pollutants intended for removal by the device.

14.6 AMENITY DESIGN

With the exception of biofiltration systems with vegetation, proprietary systems do not provide direct amenity benefits, but amenity features can often be implemented on the overlying surface, such as parks. They can also facilitate amenity provision in downstream surface features by delivering clean water. Biofiltration systems with vegetation should be designed to deliver amenity in accordance with **Chapter 18**.

14.7 BIODIVERSITY DESIGN

With the exception of biofiltration systems with vegetation, proprietary systems do not provide biodiversity benefits. They can facilitate biodiversity provision in downstream surface features by delivering clean water to those features. Biofiltration systems with vegetation should be designed to deliver biodiversity in accordance with **Chapter 18**.

14.8 PHYSICAL SPECIFICATIONS

The specification of proprietary devices will be based on manufacturers' information. This should include all relevant information that is required to ensure that the system meets the claimed performance. The specification should include the flow rates over which the claimed performance can be achieved and the range of pollutants that the system can remove. For TSS removal, the particle size and density which the system can effectively remove at a range of flow rates should be stated.

14.8.1 Pre-treatment and inlets

Proprietary systems either have their own specific inlet details or they will be fed by gullies, normal drainage systems or proprietary inlets which may provide some pre-treatment, if designed as such. Manufacturers' literature should be consulted for details of required inlets for specific devices. The maintenance requirements for any pre-treatment elements should be stated by the manufacturer, as this will have an impact on the performance of the downstream proprietary treatment system.

14.8.2 Outlets

Specific required outlet details should be provided by the manufacturer of the device.

14.9 MATERIALS

The main material that will be specific to a proprietary device will be the bespoke filter medium. The manufacturer should provide the specification for any bespoke filter medium if applicable, including:

- base material
- particle size distribution (grading)
- salt content
- permeability
- organic matter content
- pH
- electrical conductivity
- phosphorous content
- suppliers of the filter medium.

Filter media should be easily accessible for replacement, and the full specification of any cartridges should also be provided so that they can be replaced. By providing this information, there is less risk of not being able to replace the filter medium if the manufacturer of the device goes out of business, which has been a problem on some sites in the USA. If the filter medium is subject to intellectual property rights or there is competitive advantage in using a specific material then a statement that the filter medium specification will be made available – or available for acquisition under intellectual property sale – should be sufficient to ensure continuity of supply if the manufacturer ceases trading.

Material choice for the components and chambers will affect the anticipated asset lifetime. The functional performance of the device in terms of treatment should not be considered in isolation, and the long-term structural integrity, environmental impact and whole life value of the asset need to be taken into account.

14.10 LANDSCAPE DESIGN AND PLANTING

There are no landscape and vegetation requirements for most proprietary systems. For manufactured bioretention systems and tree pits, the advice in **Chapters 18 and 19** should be followed.

14.11 CONSTRUCTION REQUIREMENTS

Where units are prefabricated, construction concerns generally relate to:

1. compaction of foundations to ensure that uneven settling will not occur
2. quality control of foundation levels to ensure that inflow and outflow pipes are at the correct elevation.

Particular attention should be paid to manufacturers' information in respect of backfilling and ballasting.

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

▶ Generic health and safety guidance is presented in **Chapter 36**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

Manufacturers should provide advice on whether the treatment systems need to be protected from construction phase runoff, and how this can best be achieved.

14.12 OPERATION AND MAINTENANCE REQUIREMENTS

14.12.1 General guidance

Proprietary treatment systems will require routine maintenance to ensure continuing operation to design performance standards. Because of the wide range of different designs and performance, all manufacturers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs for any given site. The treatment performance of proprietary systems is strongly dependent on maintenance, and robust management plans will be required to ensure that maintenance is carried out in the long term. There are examples where not undertaking maintenance has led to pollution, and the companies involved have been fined. The cost of maintenance would have been much less than the subsequent fine and clean-up costs. Different proprietary treatment devices will have different operation and maintenance requirements, but this section gives some generic guidance. Ease of access for maintenance and inspection is essential. In particular, access lids and covers should be kept as lightweight as practicable.

Many proprietary systems are beneath the ground, and malfunctioning is not easy to detect, and it is therefore often ignored unless alarms are provided or the system is designed to cause localised surface ponding if full. If systems lead to other surface features, early warning of maintenance being required may be easily observed at the inlet to the feature (which should be designed to prevent it entering the main part of the component). Preference should be given to systems or designs that give some easily observable indication that maintenance is required.

Lack of routine maintenance is more likely to cause poor outflow water quality than with other SuDS due to resuspension of solids and anaerobic conditions developing within the device. For example, anaerobic conditions can develop in deep sumps and catchpits that result in nutrients and metals being released from captured sediments. During the first few months after installation, subsurface treatment units should be visually inspected after rainfall events, and the amount of deposition measured to give the operator an idea of the expected rate of sediment and oil deposition. After this initial period, systems should be inspected every six months to verify the appropriate level of maintenance. During these inspections, the floating debris and any floating oils should normally be removed. This may be done using a van-mounted system, without the need for a large tanker. Silt should be removed when it reaches 75% of the capacity of the sump. In most situations, the units should be fully cleaned out at least annually. If there is a significant spill of oil (or other pollutant) the system should be cleaned immediately.

Hilliges *et al* (2013) recommends cleaning treatment channels out every six months, in spring and after the summer. This was based on observed silt build up for a busy road (AADT 57 000 vehicles per day) and this frequency could possibly be reduced in less trafficked areas. Experience with other channels in less trafficked areas shows silt removal may only be required every 10 years.

Proper disposal of oil, solids and floating debris removed from components must be ensured, and the environmental regulator should be approached for advice where there are any doubts concerning disposal options. A small portion of water will be removed along with the pollutants during the clean-out process, which should be considered when costing sediment disposal processes.

▶ Further guidance on waste management is given in **Chapter 33**.

Harmful vapours may develop in subsurface filtration or hydrodynamic separation units, as hydrocarbons may remain there for extended periods of time. Appropriate testing for harmful vapours and venting

TABLE 14.2 An example of operation and maintenance requirements for a proprietary treatment system

Maintenance schedule	Required action	Typical frequency
Routine maintenance	Remove litter and debris and inspect for sediment, oil and grease accumulation	Six monthly
	Change the filter media	As recommended by manufacturer
	Remove sediment, oil, grease and floatables	As necessary – indicated by system inspections or immediately following significant spill
Remedial actions	Replace malfunctioning parts or structures	As required
Monitoring	Inspect for evidence of poor operation	Six monthly
	Inspect filter media and establish appropriate replacement frequencies	Six monthly
	Inspect sediment accumulation rates and establish appropriate removal frequencies	Monthly during first half year of operation, then every six months

should be undertaken whenever access for maintenance is required. Removal of oil, silt and other pollutants must be in accordance with the appropriate waste management legislation.

Maintenance responsibility for all systems should be placed with an appropriate organisation, and Maintenance Plans and schedules should be developed during the design phase.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

Table 14.2 provides guidance on the type of operation and maintenance schedule that may be appropriate for a proprietary treatment system. The list of actions is not exhaustive and some actions may not always be required.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is presented in **Chapter 36**.

14.12.2 Oil water separators

Specific requirements for oil/water separators are provided in PPG3 (EA/SEPA/EHSNI, 2006). The following items should be undertaken every six months as a minimum:

- check volume of sludge
- check thickness of light liquid
- check function of automatic closure device
- empty the separator, if required
- check the coalescing material and clean or change if necessary (class 1 only)
- check the function of the warning device (if fitted)

General inspection of the integrity of oil/water separators should occur at a maximum frequency of five years, and should cover the following:

- watertightness of system

- structural condition
- internal coatings
- in-built parts
- electrical devices and installations
- adjustment of automatic closure devices

It is usually a requirement that separators are filled with clean water before being put into operation and each time after emptying for maintenance. Failure to do so will cause the separator to malfunction until surface water builds up the required permanent water level in the facility. It is possible to fit an alarm to separators that will indicate when the collected oil volume is at a maximum, and this may be a regulatory requirement. The alarms should be placed in a location that is clearly visible to those responsible for maintenance of the system.

14.13 REFERENCES

DIBt (2011) *Approval Principles, Rainwater treatment plant. Part 1 Plant for connection with motor vehicle traffic areas of up to 2000 m^2 and treatment of waste water prior to subsequent drainage to earth and ground water*, Deutsches Institut fur Bautechnik, Berlin, Germany

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EA/SEPA/EHSNI (2006) Pollution Prevention Guidelines (PPG) 3 *Use and design of oil separators in surface water drainage systems*, Environment Agency/Scottish Environment Protection Agency, Environment and Heritage Service Northern Ireland, UK. Go to: **http://tinyurl.com/nn6ha6s**

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STATE OF NEW JERSEY (2013) *Process for approval of use for manufactured treatment devices*, New Jersey Department of Environment Protection, State of New Jersey, USA. Go to: **http://tinyurl.com/ocbqfts**

STATE OF WASHINGTON (2011) *Technical guidance manual for evaluating emerging stormwater treatment technologies: Technology Assessment Protocol – Ecology (TAPE)*, Publication No 11-10-061, Water Quality Program Department of Ecology, State of Washington. Go to: **http://tinyurl.com/oq68nz8**

USEPA (1999) *Stormwater technology fact sheet: Hydrodynamic separators*, EPA 832-F-99-017, US Environmental Protection Agency, Washington DC, USA. Go to: **http://tinyurl.com/mluoajg**

Statutes

BS EN 858-1:2002 *Separator systems for light liquids (eg oil and petrol). Principles of product design, performance and testing, marking and quality control*

Construction (Design and Management) Regulations 2015

Image courtesy Illman Young

15 FILTER STRIPS

Contents

Chapter 15

Filter strips

This chapter provides guidance on the design of filter strips – vegetated areas of gently sloping ground designed to drain runoff evenly from impermeable areas, filtering out silt and other particulates.

► *Appendix C, Section C.5.4 demonstrates how to design a filter strip for an industrial area.*

15.1 GENERAL DESCRIPTION

Filter strips (**Figure 15.1**) are uniformly graded and gently sloping strips of grass or other dense vegetation that are designed to treat runoff from adjacent impermeable areas by promoting sedimentation, filtration and infiltration (where acceptable).

The runoff is designed to flow as a sheet across the filter strip at sufficiently low velocities that treatment processes can take place effectively. They are often used as either a pre-treatment component before swales, bioretention systems and trenches (to extend the life of these components by capturing sediment) or as a treatment component (where the flow path length across the strip is sufficient).

At low to moderate velocities, filter strips effectively reduce particulate pollutant levels by removing sediments, organic materials and heavy metals. Settling-out of sediment that contains clay particles also removes absorbed nutrients and other pollutants. Some removal of free soluble pollutants in filter strips is accomplished when pollutants infiltrate into the soil, where they are subsequently taken up by rooted vegetation.

Where infiltration is possible and permitted, its extent tends to be limited during intense storms as only a small proportion of the runoff is lost (the "initial" loss), but where there is some subsoil permeability it will be the dominant mechanism for small rainfall events, and filter strips can therefore contribute effectively to the delivery of Interception.

Figure 15.1 Filter strip at motorway services draining to filter drain, Hopwood (courtesy Illman Young)

Figure 15.2 provides an example schematic for the design of a filter strip.

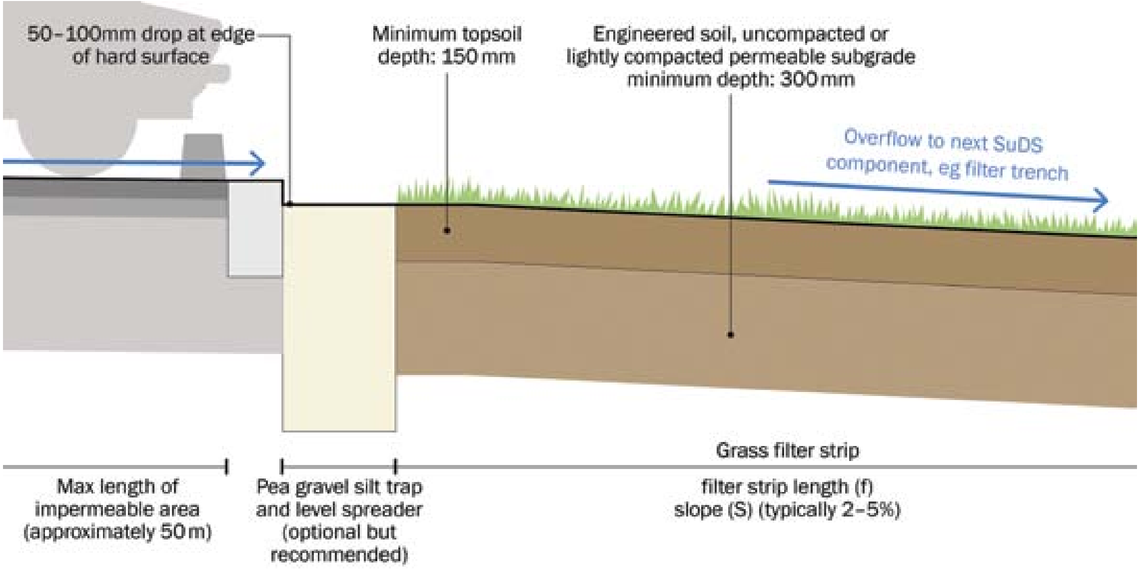

Figure 15.2 Filter strip schematic

15.2 GENERAL DESIGN CONSIDERATIONS

The contributing drainage area should have a shallow slope that falls towards the filter strip. There should not normally be any other surface gradient as filter strips require consistent sheet inflow to ensure performance, although with careful design level spreaders can be used to accommodate small changes in longitudinal slopes. The filter strip should extend the entire length of the area that is being drained.

While filter strips are a simple technology, good design requires attention to detail. Key issues that cause failure of filter strips include:

- clogging at the impervious surface/vegetation interface disturbing sheet flow
- inappropriate landscaping, for example lack of drop from edge of hard surface, inaccurate grading creating erosion and ponding conditions.

Filter strip design requirements are principally aimed at delivering water quality benefits (particularly prevention of sediment from damaging the performance of downstream components) and the filter strip performance will be strongly dependent on its length (in the direction of flow).

Filter strips will allow only low levels of infiltration so, provided that the soils between the filter strip and the groundwater provide adequate groundwater protection, and the filter strip soil has appropriate organic and clay content, then pollution risks to groundwater should usually be acceptable provided that the area is not a high hazard site. However, this should always be checked by following the requirements of **Table 4.3 in Chapter 4** and the design methods set out in **Chapter 26**. Where the sensitivity or vulnerability of the underlying groundwater means that infiltration should be prevented, filter strips can be designed above an impermeable geomembrane liner at a depth of at least 0.5 m, although risks of poor construction and waterlogging should be considered.

The acceptability of infiltration from the filter strip should be determined by following the guidance provided in **Section 25.2**, complying with all relevant requirements for infiltration systems with respect to ground stability, depth to water table etc and **Section 26.7** with respect to the protection of groundwater. The maximum likely groundwater level should always be at least 1 m below the lowest level of the filter strip, where infiltration can occur.

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

15.3 SELECTION AND SITING OF FILTER STRIPS

Filter strips can be used in a variety of situations but are particularly well suited for managing runoff from roads because they are a linear feature and easily incorporated into roadside space. They are also suitable for managing runoff from car parks and other impermeable and permeable areas. Filter strips should be effectively incorporated into landscaping and public open spaces, so that their function is not compromised by activity in the area (eg damage from parking or pedestrians).

They are useful on industrial sites because any visible pollution can be identified, the source traced, the contamination removed as far as possible and the strip rehabilitated relatively easily.

Unlined filter strips should not be used on brownfield sites unless it has been demonstrated clearly that the risk posed by leaching of contaminants is managed to acceptable levels. Unlined filter strips should not be used to treat runoff from areas with high contaminant loads if the risk of groundwater pollution due to infiltration is unacceptably high. Where a liner is used to prevent infiltration, the seasonally high groundwater level should be below the level of the liner. If infiltration is allowed, the maximum likely groundwater level should be at least 1 m below the base of the system.

Filter strips should not be located in areas where trees or structures will cause shade conditions that limit grass growth.

15.4 HYDRAULIC DESIGN

15.4.1 General

Maintaining sheet flow onto the filter strip is essential, and can effectively be achieved through the use of an appropriate level spreading device, such as a gravel flow spreader (**Section 28.4.6**).

Filter strips should be designed with a minimum longitudinal slope (ie slope along the direction of flow) of 1% (to prevent ponding) and a maximum slope of 5% to prevent flow channelling. The top and bottom of the slope should be at the lower end of the allowable slope range to reduce flow velocities and thereby reduce the risk of erosion. Where filter strip slopes are > 5%, a series of level spreaders can be used to maintain sheet flow as runoff flows over the strip.

The maximum "length" of impervious area draining to filter strips should be controlled in order to reduce the risk of concentrated flows, although this will also be dependent on the slope of the impermeable area, and on the effectiveness of adopted flow spreading techniques. Filter strip lengths tend to be determined by treatment objectives (**Section 15.5**).

Maximum flow velocities across the filter strip of 1.5 m/s are recommended to prevent erosion during design flows (note that a lower velocity is required for treatment – **Section 15.5**).

Manning's equation (**Equation 15.1**) can be used to design the filter strip for design flow velocities.

15.4.2 Interception design

Where topsoils are suitably permeable, and underlying soils have some capacity to store and/or infiltrate runoff, then filter strips with very shallow slopes can be designed to deliver Interception (ie reduce or prevent runoff during small rainfall events). The extent of Interception delivered will be strongly dependent on filter strip length (see **Figure 15.2**), which also influences designing for treatment – **Section 15.5**.

Where there is infiltration capacity, infiltration is acceptable and the strip is designed to facilitate even limited infiltration, then a check should be made to determine whether the strip is able to dispose of 5 mm rainfall depth over the contributing catchment area.

Where there is no infiltration, but the natural surface soils (or imported/re-engineered soils) have water storage capacity, then Interception design should follow the principles set out in **Section 24.8**.

15.4.3 Peak flow control design

Sheet flow across filter strips is not usually controlled, and in this situation no reduction in peak flow is included within design calculations.

To design for the control of low return period events, an impermeable berm could be designed at the toe of the slope, with piped outlets to control flow rates. Consideration of maintenance requirements, particularly in terms of pipe blockage, is required to determine whether such an approach is robust for long-term performance.

15.4.4 Volume control design

Filter strips do not tend to provide significant infiltration during large storm events, so they do not contribute to volumetric reductions during design storms.

15.4.5 Exceedance flow design

It is usual for exceedance flows (ie for events larger than the design event) to pass across the filter strip, and for any resultant damage to be repaired post event. However, if specific protection is required for downstream components, then a bypass for the strip could be considered.

15.5 TREATMENT DESIGN

Filter strips can help retain runoff from small events on site (ie deliver Interception – **Section 15.4.2**), helping to reduce the contaminant load discharged to surface waters via volumetric control. They can also treat the residual runoff by facilitating sedimentation and filtration.

The acceptability of allowing infiltration from the filter strip will depend on the extent of the likely runoff contamination and site characteristics (see **Chapter 4, Table 4.3**).

Filter strip lengths > 2.5 m (ideally 3 m) are valuable where slopes are constrained to at or near 1% (Claytor and Schueler, 1996), particularly for protecting the functionality of downstream components (ie as a pre-treatment component); and lengths > 5 m have been demonstrated to be very effective in terms of water quality performance (Barrett *et al*, 2004) even for steeper slopes, although the density of vegetation is an important factor. A filter strip study by Caltrans (2003) found that when slopes are less than 10% and the vegetation cover exceeds 80%, then an irreducible concentration is achieved at a strip length less than 5 m, ie a longer strip is only required where slopes exceed 10%. At a 20% slope, it is suggested that a 1 m length of filter strip should be provided for every 6 m of impermeable area flow path length (**Figure 15.2**).

Research has shown consistent removal of total suspended solids and total heavy metals, and frequently also for dissolved metals where designs conform to the criteria set out above. However, removal efficiencies are variable, so filter strips should always be used together with downstream treatment components. Evidence of the removal efficiencies of filter strips is presented in **Chapter 26, Annex 3**.

Good pollutant removal performance is required for all runoff events up to and including events that occur, on average, about once a year (termed here the 1:1 year event). The duration of this event should be the relevant critical duration for the filter strip flow rate. If the filter strip is draining a road, then 15 minutes is likely to be appropriate. For this water quality design event:

- the flow depth should be lower than the height of the vegetation and should therefore be limited to approximately 100 mm depth to maintain good levels of filtration
- the peak flow velocity should be lower than 0.3 m/s to promote particulate settlement
- the time of travel of runoff across the filter strip (residence time = length/velocity) should be at least 9 minutes.

In the past, there have been recommendations that keeping grass short in filter strips and swales prevents the grass lodging over (ie being pushed over and flattened by the flow of water) and improves pollution removal. However, the risk of pollution removal being compromised is now considered to be minimal, and there is no reason for a blanket requirement to keep the grass short in all swales and filter strips.

Manning's equation can be used to support the design of the filter strip, as given in **Equation 15.1**.

EQ. 15.1 Manning's equation for filter strip design

$$V = \frac{d^{2/3} S^{1/2}}{n}$$

where

V = mean cross-sectional flow velocity (m/s)

d = depth of flow (m)

S = longitudinal slope of filter strip (ie in the direction of flow) (m/m)

n = Manning's "n" roughness coefficient ($m^{-1/3}s$)

Appropriate guidance values for Manning's "n" are provided in **Section 17.4.1**.

15.6 AMENITY DESIGN

Filter strips deliver green, vegetated open space adjacent to impermeable areas and should be integrated with the overall site design and surrounding landscaping.

Where filter strips lie adjacent to roads and car parks, consideration should be given to installing a low-level, inconspicuous barrier to prevent unauthorised vehicular access onto the filter strip. This should not, however, impede sheet flow over the strip. Trees (where appropriate – **Section 15.10**), bollards, crash barriers, slotted kerbs or intermittently spaced boulders can be considered.

Landscaping and layout of the filter strip and its adjacent area should be such that pedestrian traffic (and cycling) is kept to a minimum. The location of filter strips should be well defined on a site, as their function and value to the surface water management system is often not obvious to those using the site. Consideration should be given to the potential need for suitable signage to prevent future redevelopment, or alteration and reuse, of filter strip areas.

The topsoil on which the filter strip is built should drain well and should be suitable for supporting the growth of dense vegetation, preferably grass, although other plants can be included within the design for aesthetic value (**Section 15.10**).

15.7 BIODIVERSITY DESIGN

A grass strip within the overall site landscaping will support biodiversity by providing:

- feeding and foraging areas for birds, invertebrates, reptiles and amphibians
- habitats for breeding invertebrates
- stepping stone habitats in urban areas.

More diverse planting, possibly including areas of wildflowers, will encourage wider biodiversity.

15.8 PHYSICAL SPECIFICATIONS

15.8.1 Pre-treatment and inlets

A flow spreading device should normally be included upstream of the filter strip to ensure consistent lateral inflow along the length of the device. Some of these can also provide some degree of pre-treatment by trapping sediment upstream of the strip. Flow spreading options include:

- porous pavement strips
- stabilised turf strips
- slotted curbing
- gravel-filled trenches (with larger stones where the contributing drainage area is steep), and
- concrete sills.

There should always be a drop of at least 50 mm from the pavement edge to the filter strip to prevent the formation of a sediment lip.

All pre-treatment/flow spreading devices should be designed with maintenance considerations in mind.

15.8.2 Outlets

In most situations, the outflow from the filter strip should be routed into a downstream component (eg swale) for conveyance and further treatment, so no outlet mechanism is required.

15.9 MATERIALS

15.9.1 Level spreaders

Any interim level spreaders should be constructed of durable, non-toxic material graded into the soil – minimum 150 mm wide, 50–100 mm high, running along the length of the filter strip.

15.9.2 Subsoils

If subsoils are highly compacted or of such low fertility or soil composition that pore space for water storage is very low and vegetation is unlikely to become established, the soils should be tilled to 300 mm and amended to meet the specifications for engineered soils set out in **Section 30.4.2**.

15.9.3 Geotextiles/geomembranes

▶ Geotextile and geomembrane specifications are presented in **Section 30.5**.

15.10 LANDSCAPE DESIGN AND PLANTING

The filter strip surface should be planted with an appropriate grass mixture, or turfed. Filter strips are subject to both wet and dry conditions, as well as sediment and debris accumulation. A mixture of dry-area and wet-area grasses, able to prevent erosion and capable of growing through any silt deposits is required. A dense, soil binding, deep rooted vegetation cover is required – that will need to be maintained at lengths of 75–150 mm to ensure effective filtration performance during regular events. Turf provides immediate protection, provided the seams are protected by laying the strips perpendicular to the flow of water and hand tamping them after laying. A filter strip is best seeded during spring and early summer months to give vegetation the whole length of a growing season to establish. Longer grasses and wildflower areas, if considered beneficial for other reasons, are not considered to pose a significant risk to performance.

Where filter strips are used to drain runoff from roads or car park areas that are likely to be regularly salted during winter months, then the planting should be salt tolerant.

Trees and dense scrub should generally be avoided on the filter strip unless the available filter strip flow path length is significantly greater than required (eg parks and schools where open space areas may be large). Although they may improve aesthetics, it is difficult to preserve the healthy dense vegetated ground cover, slope uniformity and stability that are required for a well-functioning filter strip. Where additional space is available and the risks to filter strip performance have been fully considered, trees can potentially be used either as traffic barriers or as amenity features.

Filter strips should not be located in shaded areas because sunlight is required to ensure healthy plant growth.

If a berm is constructed at the toe of the filter strip, the vegetation should be resistant to frequent inundation within the shallow ponding limit.

Fertilising a filter strip should be avoided if possible, particularly where the receiving environment is sensitive to nutrient loadings.

▶ Landscape design and planting best practice is presented in detail in **Chapter 29**.

15.11 CONSTRUCTION REQUIREMENTS

Filter strips should be clearly marked before site work begins and protected by signage and silt fencing, to avoid their disturbance during construction. No vehicular traffic, except that specifically used to construct the component, should be allowed close to the filter strip. Excavating equipment should operate from the side of the filter strip. If compaction of soils does occur, a 300 mm depth of soil should be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth or tilled and enhanced to achieve a similar specification.

The filter strip should be constructed using careful grading techniques to provide an even and consistent longitudinal slope, with no severe undulations that will cause localised ponding or promote flow in channels. Even the smallest non-conformities may compromise flow conditions.

A newly constructed filter strip should be protected from surface water flows until vegetation has been established. This may be achieved by:

- diverting runoff around the filter strip until vegetation is established
- using pre-established turf or seeded mattresses
- covering the filter strip with clear plastic until the vegetation is well rooted
- placing an erosion control blanket over the freshly applied seed mix.

Ideally filter strips should be planted in the spring, when vegetation can become established with minimum irrigation needs. If more than 30% of the treatment area is bare after four weeks, reseeding or replanting will be required to achieve 90% coverage.

If sediment from construction work accumulates on a filter strip, it should be cleared and the strip fully rehabilitated before the drainage system is adopted by the organisation carrying out the maintenance.

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

▶ Generic health and safety guidance is presented in **Chapter 36**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

15.12 OPERATION AND MAINTENANCE REQUIREMENTS

Filter strips will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of filter strips is dependent on maintenance, and robust management plans will be required to ensure that maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance.

Maintenance of filter strips is relatively straightforward for landscape contractors and typically there should only be a small amount of extra work (if any) required for a filter strip over and above what is necessary for standard public open space. Providing landscape management is already required at site, filter strip maintenance should therefore have marginal cost implications. However, regular inspection and maintenance is important for the effective operation of filter strips as designed. Maintenance responsibility for a filter strip should always be placed with an appropriate organisation. If filter strips are implemented within private property, owners should be educated on their routine maintenance needs, and should understand the long-term Maintenance Plan and any legally binding maintenance agreement.

Access for maintenance vehicles should always be available. However, this is not usually a constraint due to the likely location of the filter strip adjacent to impermeable areas. Litter and debris removal should be undertaken as part of general landscape maintenance for the site and before any other SuDS management task. All litter should be removed from site.

The major maintenance requirement for filter strips is mowing. This should ideally retain grass lengths of 75–150 mm across the main "treatment" surface to assist in filtering pollutants and retaining sediments and to reduce the risk of flattening during runoff events. However, longer vegetation lengths, where appropriate, are not considered to pose a significant risk to functionality.

Grass clippings should be disposed of either off site or outside the area of the filter strip to remove nutrients and pollutants. All vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Occasionally, sediment will need to be removed (eg once deposits exceed 25 mm in depth), although this can be minimised by ensuring that upstream areas are fully stabilised in advance. Available evidence from monitoring studies indicates that small distributed infiltration practices such as filter strips do not contaminate underlying soils, even after more than 10 years of operation (TRCA, 2008). Sediments excavated from a filter strip that receives runoff from residential or standard road and roof areas are generally not of toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For runoff from streets with high vehicle traffic, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site if there is an appropriate safe and acceptable location to do so.

Any damage due to sediment removal or erosion should be repaired and immediately reseeded or planted.

▶ Further detail on waste management is provided in **Chapter 32**.

Table 15.1 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

TABLE 15.1 Operation and maintenance requirements for filter strips

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the grass – to retain grass height within specified design range	Monthly (during growing season), or as required
	Manage other vegetation and remove nuisance plants	Monthly (at start, then as required)
	Inspect filter strip surface to identify evidence of erosion, poor vegetation growth, compaction, ponding, sedimentation and contamination (eg oils)	Monthly (at start, then half yearly)
	Check flow spreader and filter strip surface for even gradients	Monthly (at start, then half yearly)
	Inspect gravel flow spreader upstream of filter strip for clogging	Monthly (at start, then half yearly)
	Inspect silt accumulation rates and establish appropriate removal frequencies	Monthly (at start, then half yearly)
Occasional maintenance	Reseed areas of poor vegetation growth; alter plant types to better suit conditions, if required	As required or if bare soil is exposed over > 10% of the filter strip area.
Remedial actions	Repair erosion or other damage by re-turfing or reseeding	As required
	Relevel uneven surfaces and reinstate design levels	As required
	Scarify and spike topsoil layer to improve infiltration performance, break up silt deposits and prevent compaction of the soil surface	As required
	Remove build-up of sediment on upstream gravel trench, flow spreader or at top of filter strip	As required
	Remove and dispose of oils or petrol residues using safe standard practices	As required

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the filter strip should be monitored, and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is presented in **Chapter 36**.

15.13 REFERENCES

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Statutes

Construction (Design and Management) Regulations (CDM) 2015

Image courtesy Aco Limited

16 FILTER DRAINS

Contents

Chapter 16

Filter drains

This chapter provides guidance on the design of filter drains – linear drains consisting of a trench filled with a permeable aggregate material, often with a perforated pipe in the base of the trench to assist drainage.

► *Appendix C, Section C.5.4 demonstrates how to design a filter drain for an industrial area.*

16.1 GENERAL DESCRIPTION

Filter drains are shallow trenches filled with stone/gravel that create temporary subsurface storage for the attenuation, conveyance and filtration of surface water runoff. The stone may be contained in a simple trench lined with a geotextile, geomembrane or other impermeable liner, or within a more structural facility such as a concrete trough. Filter drains may be lined (if required) or may allow infiltration depending on the suitability of the underlying soils and the protection they afford to the groundwater (**Sections 25.2 and 26.7**).

Filter drains should ideally receive lateral inflow from an adjacent impermeable surface that is pre-treated using a vegetated filter strip or equivalent. They are not normally intended to function as sediment traps and should be implemented downstream of a pre-treatment system in order to prevent clogging and failure. Where there is no effective upstream removal of sediments and silts, a geotextile (or other effective filtration) layer below the filter drain surface, at a shallow depth, is required that can be regularly removed and cleaned or replaced.

Filter drains can help reduce pollutant levels in runoff by filtering out fine sediments, metals, hydrocarbons and other pollutants. They can also encourage adsorption and biodegradation processes. With adequate structural protection, geocellular products can be used as an alternative to some of the stone where the component is designed principally for conveyance: they have a higher void ratio but limited treatment capacity, and are often used to provide additional storage zones for high return period flow events in conjunction with other treatment components or gravel layers in the trench.

Filter drains are on-line features, and designers should therefore take full consideration of the inflow rates and volumes potentially associated with high return period events, ensuring that the trench is adequately protected from damage, and excess flows can be conveyed safely downstream.

A perforated pipe should be provided near the base of the filter drain to collect and convey water to downstream drainage components. Use of the available attenuation storage provided by the voids in the aggregate fill can be maximised through the use of downstream flow control systems. A high-level perforated pipe can be installed to provide an overflow for flows in excess of the design event. Where a network of filter drains is established, high-level pipes can be used to transfer excess waters around the system in the event of local overloading.

Filter drains can replace conventional pipework as conveyance systems, and the use of adjacent filter strips or flow spreaders can remove the need for kerbs and gullies when systems are located adjacent to roads or highways. They work best when incorporated into a treatment train, and should be used in conjunction with other SuDS components to safely pass and store extreme storm flows.

Figure 16.1 Examples of filter drains (courtesy Hydro International and Illman Young)

An example cross section for a filter drain is given in **Figure 16.2**. The upper sacrificial stone layer may only be required where upstream sediment removal is considered insufficient.

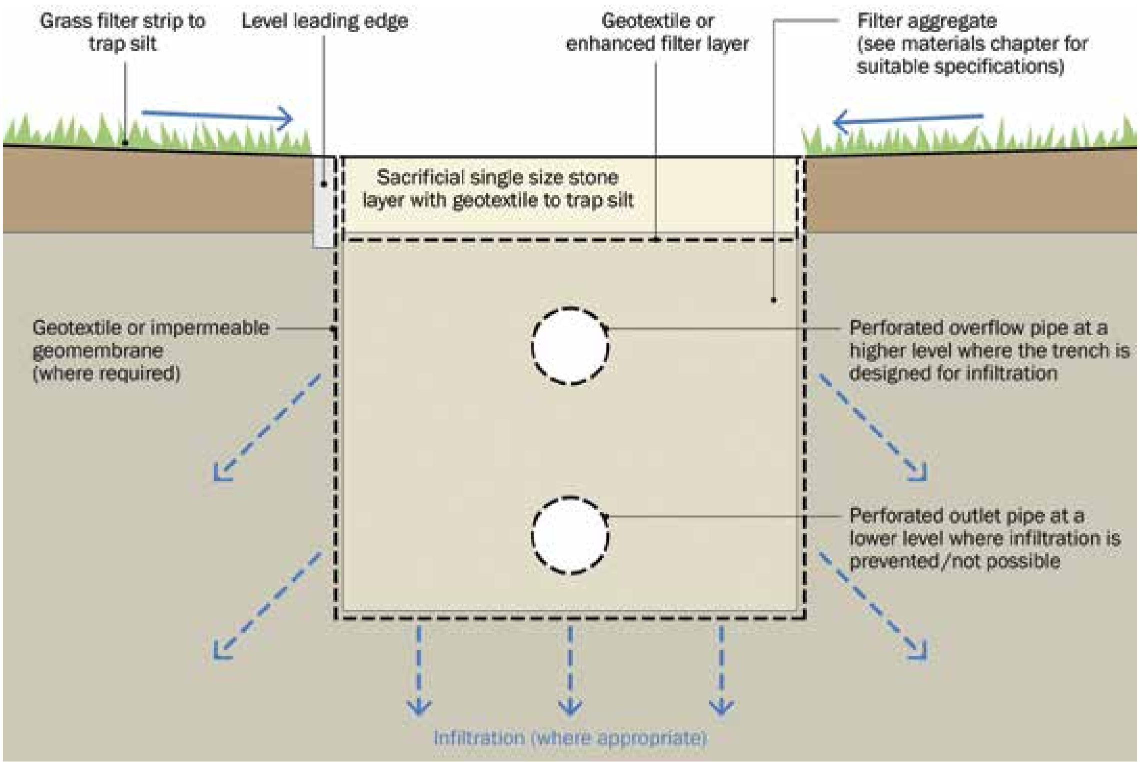

Figure 16.2 Filter drain schematic

16.2 GENERAL DESIGN CONSIDERATIONS

Filter drain depths should generally be 1–2 m. The minimum depth of filter medium beneath any inflow distribution pipework and outfall collection systems should be 0.5 m to ensure reasonable levels of pollutant removal (Hatt *et al*, 2007). Where infiltration is allowed, the maximum groundwater level should be at least 1 m below the base of the trench. Where filter drains are implemented adjacent to roads, guidance on gradients and distances to carriageway centrelines are set out in **Chapter 9**. Filter drain widths will tend to be dictated by the flows to be accommodated by the component and the diameter of any embedded pipe (eg a 150 mm diameter pipe would require 150 mm width bedding surround, giving a total filter drain width of 450 mm).

The voids ratio and permeability of the granular fill should be sufficiently high to allow adequate percolation and to control the risk of blockage. Consideration should be given as to whether the trench is required to withstand surface loadings such as vehicular traffic, as this will influence the type of fill that will be suitable. The structural requirements of geocellular systems (which may be specified for enhanced storage or conveyance purposes beneath the stone layer) are described in detail in **Chapter 21**. Such systems should be below the minimum 0.5 m depth required for adequate pollutant removal or else additional downstream (or upstream) treatment will usually be required. Where perforated pipes are used as distribution or collection systems, they should be set within appropriate depths of pipe bedding material. Perforated pipes require a sufficient area of openings to manage the expected flow rate of water into and out of the pipes.

The most effective pre-treatment option for filter drains is to have runoff flow over a small filter strip between the edge of the drained area and the trench. Even a 0.5 m wide strip of grass can remove a significant amount of silt and prolong the time until the drain needs to be cleaned/rehabilitated. An enhanced filter layer or geotextile can be used at a high level in the trench to provide pre-treatment where other pre-treatment options are not practicable. However, this should only be used where inspection and maintenance regimes are regular and robust, as the system will tend to clog rapidly. Also, the layer should be readily separable from the side sections as it will require regular replacement. The filter drain should only drain small areas if this form of pre-treatment is adopted.

▶ Appropriate geotextile and geomembrane specifications are described in the **Chapter 30**.

The main cause of damage to filter drains is vehicles running off the carriageway and scattering the filter material. This can cause a hazard to vehicles on the carriageway, and barriers such as bollards, large rocks or low railings should be used to prevent traffic from running on, or parking on, the filter drain.

For all filter drains, any lengths of perforated pipes that are more than 10 m should be spaced between access sumps (also known as catchpits) so that the pipes can be cleaned by jetting out or rodding (these sumps can be up to 90 m apart for longer runs of trench). Access sumps should always be accessible and clearly identifiable.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

16.3 SELECTION AND SITING OF FILTER DRAINS

Filter drains are best located adjacent to impermeable surfaces such as car parks or roads/highways with upstream pre-treatment systems. They can be used for draining residential and non-residential runoff and, when lined, can be used to manage surface water runoff from areas with high groundwater pollution risks. Unless effective pre-treatment of sediments is included within the design, they are applicable primarily to impervious areas where there are not high levels of particulates in the runoff.

Filter drains are generally appropriate for catchments with small impermeable areas. They can be effectively incorporated into the landscape and public open spaces, and with careful design can have minimal land-take requirements. They are not usually used as retrofit components due to potential obstruction and interference with service routes.

The use of filter drains is typically restricted to sites without significant slopes, unless they can be placed parallel to contours. The longitudinal slope should not exceed 2% because low velocities are required for stable conveyance through the filter medium and for pollutant removal processes to occur.

Filter drains should not be sited on unstable ground, and ground stability should be verified by assessing site soil and groundwater conditions. They are designed for intermittent flow and should be allowed to drain and re-aerate between rainfall events. They should not, therefore, be used on sites with a continuous flow from groundwater or other sources.

Filter drains can prove a useful surface water management component on sites where vegetated systems are impractical. They could be constructed beneath impermeable surfacing, provided that sufficient access is included for inspection and maintenance, or grassed/vegetated surfacing, provided that an appropriate means of identifying and locating the trench is included within the design.

16.4 HYDRAULIC DESIGN

16.4.1 General

There are three elements to the design of filter drains:

1 design of the filter material for adequate percolation of water – the rate of percolation is a compromise between pollutant removal and the need to restrict the risk of flooding in the catchment for the design storm event, and to act as an appropriate trickling filter for small events, contact time with the aggregate should be maximised (via geometric design characteristics)

2 design of the filter material to store water – the greater the void ratio, the more storage is available in the trench, and the level of storage available will depend on the throttle at the outlet

3 design of the pipe system to convey water

The rate of percolation of water through the filter material can be estimated roughly using Darcy's law. The rate of percolation should be sufficient to meet the design criteria. The storage of water within the trench and aggregate is dependent on the void ratio of the aggregate and the downstream throttle rate. Calculation methods are as for pervious pavements, as set out in **Section 20.5**.

The slotted pipe in the base of the filter drain should be designed using conventional pipe design methods to achieve the flows required to meet the site-specific design criteria (**Equation 20.2**). The perforations in the pipe should be sufficient to provide adequate flow in the same way as for bioretention systems in **Section 18.8.2**.

16.4.2 Interception design

Filter drains can only deliver a small contribution to Interception (the prevention of runoff for the majority of small events) where they do not allow infiltration. Some water will soak into the filter medium and will also be removed by evapotranspiration and infiltration (where allowed) even if permeability levels are very low. The extent of the volumetric reduction in runoff will depend on the infiltration rate of the surrounding soil, the catchment area, area and depth of the system, type of vegetation and the climate.

▶ Interception design methods are set out in **Section 24.8**.

16.4.3 Peak flow control design

As well as determining the degree of filtration, the particle size of the medium also determines travel time in the filter and can therefore play a role in meeting peak flow discharge rate control requirements.

Filter drains can help to manage peak flows by naturally limiting rates of conveyance through the filter medium, and also by providing attenuation storage which fills when the rate of flow at the outlet is controlled. Design and assessment of the surface and subsurface storage volumes can be determined using standard hydraulic assessment.

Subsurface storage can be provided by the void space in the filter medium and/or drainage layer in the system, ie:

Available attenuation storage in the filter medium and drainage layer of the bioretention system = Volume of system × void ratio in the soil/drainage layer

Due to the small runoff areas likely to be discharging to the system, it may be appropriate to link adjacent systems together so that the size of the opening in the flow control can be larger.

16.4.4 Volume control design

Contribution of filter drains to volume control should be evaluated using standard methods – based on expected infiltration rates and/or available attenuation storage and specified flow controls. Assessment of volumetric control should follow the normal hydraulic assessment methods in **Chapter 24**.

16.4.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the filter drain. This can be achieved by installing an overflow pipe or weir/overflow structure above the design water storage level to convey excess flows downstream.

The exceedance flow capacity of the overflow should be confirmed using normal hydraulic assessment methods and analysis (weir, orifice and pipe flow). Exceedance flows beyond the capacity of the overflow should also be confirmed.

Ideally, exceedance flows should be designed to bypass the filter drain, but where the exceedance flow structure is within the trench it should be located as close to the inlet as possible to minimise the flow path length for above-capacity flows (reducing the risk of scouring) (**Section 18.8.2**).

Figure 16.3 Filter drain with exceedance event managed within play area, Exwick, Devon (courtesy Robert Bray Associates)

16.5 TREATMENT DESIGN

Unless infiltration is allowed, filter drains will not provide a significant reduction in contaminant loads to surface waters via volumetric runoff control, as they can only provide limited Interception (**Section 16.4.2**). The acceptability of allowing infiltration from the filter drain will depend on the extent of the likely runoff contamination and site characteristics (see **Chapter 4, Table 4.3**).

Hatt *et al* (2007) reported gravel filters to be an effective treatment option for runoff, where treatment of sediment and heavy metals is of principal concern. Performance efficiencies reported by Hatt *et al* (2007) were greater than 90% for TSS and generally 60–80% for heavy metals. However, the rate of clogging related to these efficiencies is not given, and clogging may act to enhance perceived efficiencies. Similar performance efficiencies are suggested by Higgins *et al* (2008).

Unless regular monitoring and regular gravel filter removal and washing can be accommodated, it is not recommended to use filter drains as a sediment capture mechanism.

▶ Further evidence relating to potential performance efficiencies of filter drains is presented in **Chapter 26, Annex 3**.

Good pollutant removal performance is required for all runoff events up to and including events which occur, on average, about once a year (termed here the 1:1 year event). The duration of this event should be the relevant critical duration for the filter drain flow rate. If the filter drain is draining a road, then 15 minutes is likely to be appropriate. For this water quality design event, flows should be captured by the drain and then flow towards the outfall at low rates to maximise contact time with the gravel.

An additional filter layer can be added to provide enhanced treatment by using materials such as sand, granular activated carbon, leaf compost or pea gravel, although this is not routine design practice and is likely to be expensive. Coarser materials allow faster transmission of water, but finer media will filter particles of a smaller size. Sand has been found to be a good balance, but different types of media have different contaminant removal efficiencies. Sand is reliable at removing TSS, but organic soils are better at heavy metal and phosphorous removal.

16.6 AMENITY DESIGN

Filter drains can be designed creatively to provide attractive boundary lines or edging.

Filter drains may be protected with geotextile and covered with topsoil and planted with grass, in a landscaped area. However, this increases the risk that maintenance responsibilities will be overlooked, which could cause performance failure of the system and should therefore be implemented with caution. However, overlying grass may help reduce clogging risks on the trench surface.

Figure 16.4 Filter drain with planting, Exwick, Devon (courtesy Robert Bray Associates)

16.7 BIODIVERSITY DESIGN

Gravel media can host microorganisms and provide breeding grounds for insects and amphibians. Adjacent biodiverse planting or overlying grass (**Section 16.6**) can also deliver additional opportunities for biodiversity.

16.8 PHYSICAL SPECIFICATIONS

16.8.1 Pre-treatment and inlets

The design, operation and maintenance of filter drain inlet structures and pre-treatment systems is a key factor in their continued satisfactory operation. Sheet flow from an adjacent impermeable area should pass over a vegetated filter strip (**Chapter 15**). For point inflows, pre-treatment should consist of a sediment forebay or silt trap or other SuDS system (eg swale) that is easily maintained. Roof waters can be connected directly through sediment/debris traps. Exit velocities from the pre-treatment system to the trench should be non-erosive.

- ▶ The design of inlet structures is set out in detail in **Chapter 28**.

16.8.2 Underdrains and outlets

Filter drains should be designed with low-level outfalls with appropriate flow control devices. Outlet erosion protection is unlikely to be required as flows are likely to be low. Unless the component is an off-line device, the system should be designed with appropriate overflow facilities so that design flows can be conveyed safely downstream.

16.9 MATERIALS

- ▶ Specifications for filter media and gravel media layers are provided in **Chapters 18 and 30**.
- ▶ Specifications for geotextiles and geomembranes are provided in **Chapter 30**.

16.10 LANDSCAPE DESIGN AND PLANTING

Filter drains should be integrated within the surrounding space in an attractive and complementary way, using vegetation to enhance their appearance where appropriate.

- ▶ Landscape design and planting best practice is presented in **Chapter 29**.

16.11 CONSTRUCTION REQUIREMENTS

Filter drains should be protected before completion and stabilisation of the upstream development areas. They should not be used for drainage of construction sites, where untreated runoff is likely to contain large amounts of silt, debris and other pollutants, as this will cause rapid clogging of the systems.

All trench excavations should follow construction best practice and be supported, if required. No personnel should be allowed to enter an unsupported trench deeper than 1.2 m. Trench supports should be designed to guarantee the safety of those working in the trench. Support may also be needed for shallower trenches in weak ground.

Filter drain formations should be flat or to a shallow grade to reduce the risk of ponding and negative filter gradients. Geotextile and stone fill should be clean before construction. Backfill should be placed in 100–150 mm layers and lightly compacted as required.

All geotextiles should be wrapped and secured to prevent gravel or stone from clogging with sediments.

The drain-down time after a storm should be observed after completion or modification of the facility to confirm that the desired drain time has been obtained (BRE, 1991).

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety guidance is presented in **Chapter 36**.

16.12 OPERATION AND MAINTENANCE REQUIREMENTS

Filter drains will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of filter drains is dependent on maintenance, and robust management plans will be required to ensure that maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance.

Regular inspection and maintenance is important for the effective operation of filter drains as designed. Maintenance responsibility for a filter drain should always be placed with an appropriate organisation. Adequate access should always be provided to the filter drain for inspection and maintenance. If filter drains are implemented within private property, owners should be educated on their routine maintenance needs, and should understand the long-term Maintenance Plan and any legally binding maintenance agreement.

Litter (including leaf litter) and debris removal should be undertaken as part of general landscape maintenance for the site and before any other SuDS management task. All litter should be removed from site.

Table 16.1 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

TABLE 16.1 Operation and maintenance requirements for filter drains

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter (including leaf litter) and debris from filter drain surface, access chambers and pre-treatment devices	Monthly (or as required)
	Inspect filter drain surface, inlet/outlet pipework and control systems for blockages, clogging, standing water and structural damage	Monthly
	Inspect pre-treatment systems, inlets and perforated pipework for silt accumulation, and establish appropriate silt removal frequencies	Six monthly
	Remove sediment from pre-treatment devices	Six monthly, or as required
Occasional maintenance	Remove or control tree roots where they are encroaching the sides of the filter drain, using recommended methods (eg NJUG, 2007 or BS 3998:2010)	As required
	At locations with high pollution loads, remove surface geotextile and replace, and wash or replace overlying filter medium	Five yearly, or as required
	Clear perforated pipework of blockages	As required

Sediments excavated from upstream pre-treatment devices that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate waste management protocols and compliance with legislation. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site, if there is an appropriate safe and acceptable location to do so. Any damage due to sediment removal or erosion should be repaired and immediately reseeded or planted.

▶ Further detail on waste management is provided in **Chapter 32**.

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the filter drain should be monitored and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is presented in **Chapter 36**.

16.13 REFERENCES

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Construction (Design and Management) Regulations (CDM) 2015

17 SWALES

Contents

Chapter 17 Swales

This chapter provides guidance on the design of swales – shallow vegetated channels designed principally to convey and treat runoff.

- *Appendix C, Section C.5.4 demonstrates how to design an underdrained swale for an industrial area.*
- *Appendix C, Section C.5.5 demonstrates how to design a strategic conveyance swale.*

17.1 GENERAL DESCRIPTION

Swales are shallow, flat bottomed, vegetated open channels designed to convey, treat and often attenuate surface water runoff. When incorporated into site design, they can enhance the natural landscape and provide aesthetic and biodiversity benefits. They are often used to drain roads, paths or car parks, where it is convenient to collect distributed inflows of runoff, or as a means of conveying runoff on the surface while enhancing access corridors or other open space. Swales can have a variety of profiles, can be uniform or non-uniform, and can incorporate a range of different planting strategies, depending upon the site characteristics and system objectives.

Swales can replace conventional pipework as a means of conveying runoff, and the use of adjacent filter strips and/or flow spreaders can also remove the need for kerbs and gullies.

The standard swale channel is broad and shallow and covered by vegetation, usually grass, to slow the water – facilitating sedimentation, filtration through the root zone and soil matrix, evapotranspiration and infiltration into the underlying soil. A swale can have check dams or berms installed across the flow path, that temporarily pond runoff to increase pollutant retention and infiltration and further decrease flow velocity – particularly useful for sites with steeper gradients.

There are three types of swale, described in **Sections 17.1.1 to 17.1.3**.

17.1.1 Conveyance and attenuation swale

The conveyance swale is a shallow vegetated channel (**Figure 17.1**). These are particularly effective ways of collecting and conveying runoff from the drained area to another stage of the SuDS Management Train. They can be designed for treatment and/or attenuation (where required), depending on the level of flow constraint and ponding depths delivered by the design.

Very small swales ("mini-swales") can be used to manage small events with effective overflow facilities to alternative components.

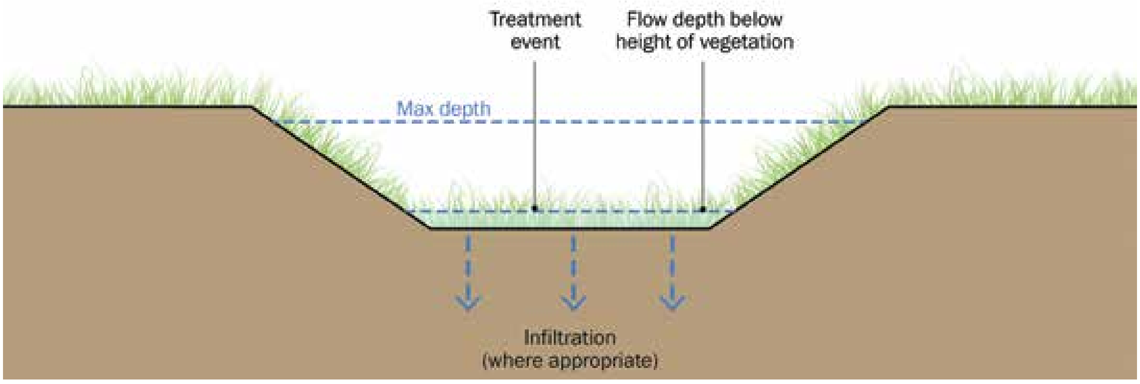

Figure 17.1 Typical conveyance/attenuation swale

17.1.2 Dry swale (or "enhanced" swale)

The dry swale is a vegetated conveyance channel, designed to include a filter bed of prepared soil that overlays an underdrain system (**Figure 17.2**). This underdrain provides additional treatment and conveyance capacity beneath the base of the swale, and prevents waterlogging. To prevent infiltration, or where groundwater levels are high, a liner could be introduced at the base.

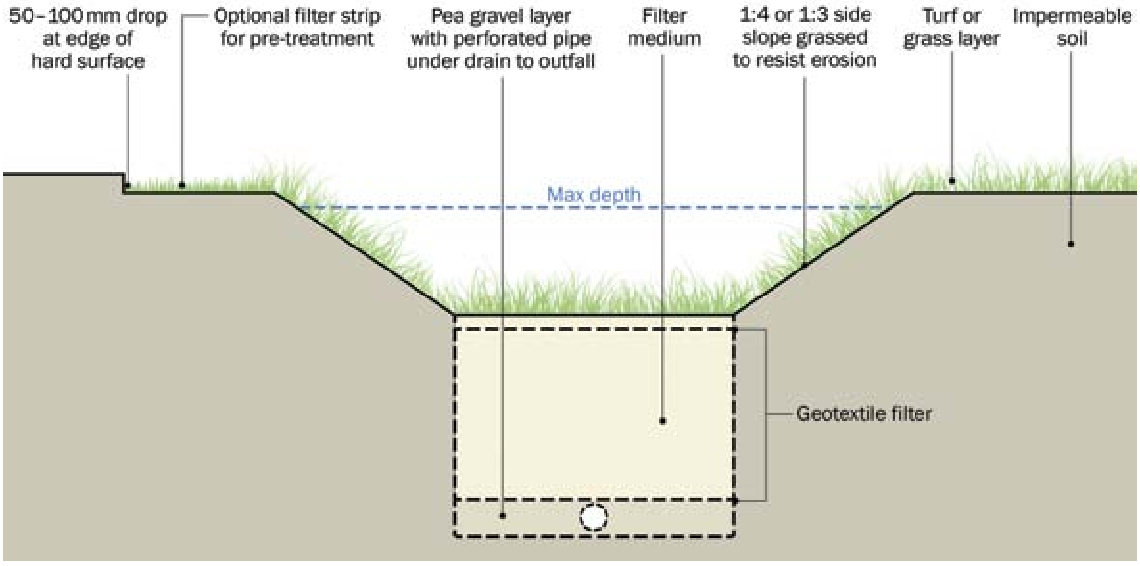

Figure 17.2 Typical dry swale

17.1.3 Wet swale

This system is equivalent to the conveyance swale, but is designed specifically to deliver wet and/or marshy conditions in the base (**Figure 17.3**). They can be used where sites are very flat and soils are poorly drained and/or to deliver the functionality or amenity or biodiversity requirements of a longitudinal pond/wetland component. Specific wetland planting will be required for the swale base.

A typical swale plan view is given in **Figure 17.5**.

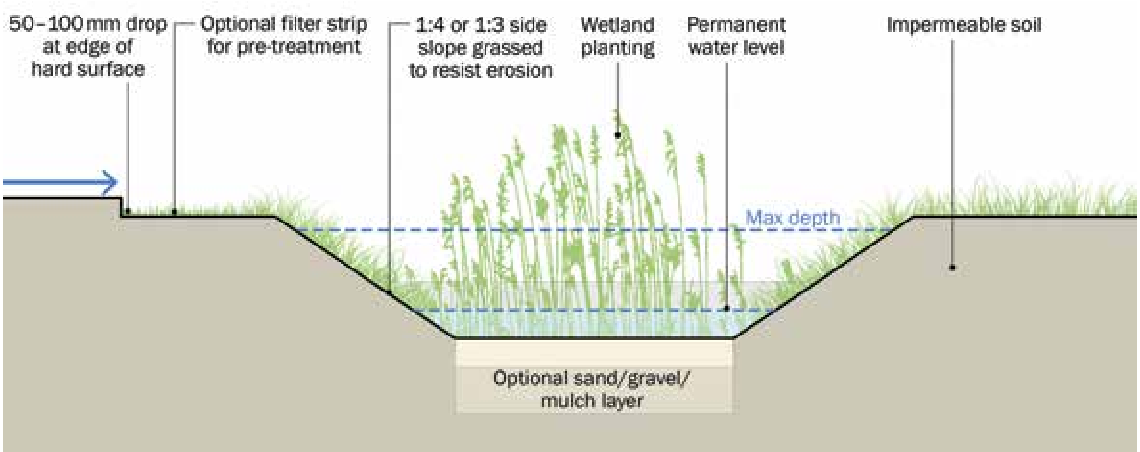

Figure 17.3 Typical wet swale

Figure 17.4 Examples of different swale types and designs

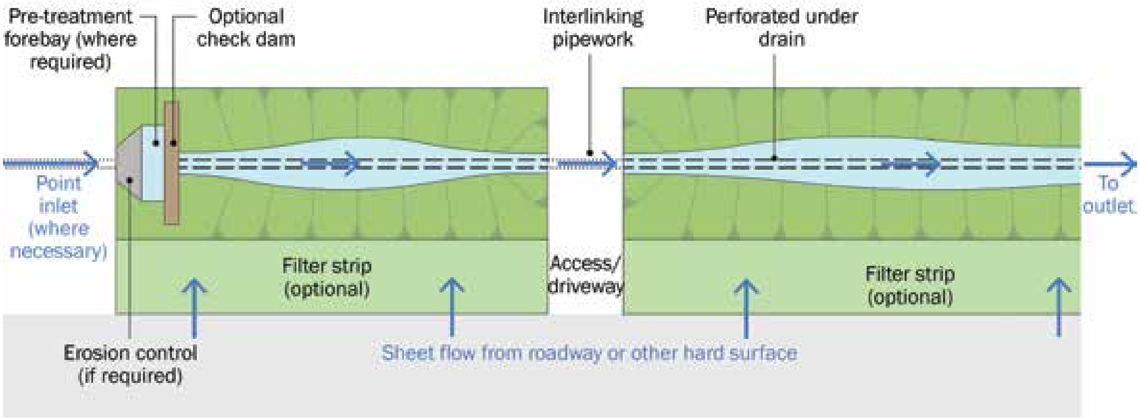

Figure 17.5 Typical plan view of a swale

17.2 GENERAL DESIGN CONSIDERATIONS

Swales should generally be designed with a trapezoidal or parabolic cross-section as these are easiest to construct and maintain, and offer good hydraulic performance.

Grass swales should generally be designed with a bottom width of 0.5–2.0 m, although narrower or wider swales may be used, subject to suitable assessment. The design width should allow for shallow flows and adequate water quality treatment (**Section 17.5**), while preventing flows from concentrating and creating erosion channels. For swale widths > 2 m where the width of flow may lead to flow channelling, consideration should be given to the need to divide the cross-section with a flow divider, using a flow spreader at the inlet for each side if required.

Longitudinal slopes should be constrained to 0.5–6%. Check dams should be incorporated on slopes greater than 3% (which may allow slopes to increase up to 10%) and permanent reinforcement matting should be considered where velocities are above those recommended for standard designs. Underdrains are required for conveyance swales with a slope of < 1.5% or wet swales can be considered for such scenarios.

The side slopes should be as flat as possible to aid pre-treatment of lateral incoming flows by maximising the swale filtering surface, to enhance safety and allow easy access for mowing. Steeper side slopes are likely to experience erosion channelling from incoming lateral flows. A maximum slope of 1 in 3 (33%) is recommended and a 1 in 4 (25%) slope is preferred where space permits as this makes mowing easier. Side slopes may be increased, provided all technical and safety implications have been fully considered.

When used to convey and treat road runoff, the swale length simply parallels the road, and therefore should be equal to, or greater than, the contributing roadway length. The length of any section of swale between culverts (eg road/drive crossings) should be 5 m or greater for maintenance access purposes. Otherwise, the length will be that required for water quality treatment design functionality and will be a function of the site constraints and hydraulic properties of the swale in any particular location.

The normal maximum swale depth is 400–600 mm. This can be increased where deemed acceptable by a health and safety risk assessment (**Chapter 36**). The depth of swale may be dependent on the depth of required inflow pipework, for example from a permeable pavement sub-base or other upstream component. Where the inlet depth would make the swale inappropriately deep, consideration can be given to discharging directly to the swale underdrain and utilising the conveyance capacity of the swale for larger events – provided there is a free route for water to rise into the swale. In such a scenario, the swale could not be used to provide treatment for regular events, so alternative treatment methods would be required. Deep swales will tend to mean higher land-take requirements, deeper water and costly excavations – and alternative options should potentially be considered to ensure that the optimum surface water management system is delivered.

Where swales allow only low levels of infiltration (ie are designed as conveyance components), provided the soils between the swale and the groundwater provide adequate groundwater protection, and the swale soils have appropriate organic and clay content, then pollution risks to groundwater should usually be acceptable provided the area is not a high hazard site. However, this should always be checked by following the requirements of **Table 4.3 in Chapter 4** and the design methods set out in **Chapter 26**. Where the sensitivity and/or vulnerability of the underlying groundwater means that infiltration should be prevented, swales can be designed above an impermeable geomembrane liner at a depth of at least 0.5 m, although risks of poor construction and waterlogging should be considered.

The acceptability of infiltration from the base of the swale should be determined by following the guidance provided in **Section 25.2**, complying with all relevant requirements for infiltration systems with respect to ground stability, depth to water table etc, and **Section 26.7** with respect to the protection of groundwater. The maximum likely groundwater level should always be at least 1 m below the lowest level of the swale, where infiltration can occur.

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

17.3 SELECTION AND SITING OF SWALES

Swales can be used in a wide variety of situations. They are well suited for managing runoff from roads because they are a linear feature and easily incorporated into the roadside space. They are also suitable for managing runoff from car parks and other impermeable and permeable areas. Swales should be incorporated into landscape and public open spaces, as they tend to demand significant land-take due to their shallow side slopes. Swales are generally difficult to incorporate into dense urban developments where space is limited, although steeper side slopes may be appropriate in some situations – for example, a very shallow (150 mm deep) swale or a suitably fenced or inaccessible swale edge can have steeper or even vertical slopes (**Figure 17.6**).

They are ideal for use on industrial sites (lined and with additional downstream treatment components) because any pollution that occurs is visible and can therefore be dealt with before it causes damage to the receiving watercourse. They are also much easier to maintain on sites with high sediment loads than any other type of component. They should not be located in areas where there are particular risks of excess fertiliser or weed-killer application which could cause pollution of runoff.

Unlined swales should not be used on brownfield sites unless it has been demonstrated that the risk posed by leaching of contaminants is managed to acceptable levels. Unlined swales should not be used to treat runoff from areas with high contaminant loadings if the risk of groundwater pollution due to infiltration is unacceptably high. Where a liner is used to prevent infiltration, the seasonally high groundwater level should be below the level of the liner. If infiltration is allowed, the maximum likely groundwater level should be at least 1 m below the base of the system.

Swales should not be located where extensive areas of trees or overhead structures will cause shade conditions that could limit growth of grass (or other vegetation).

Figure 17.6 Swale with vertical side (courtesy EPG Limited)

17.4 HYDRAULIC DESIGN

17.4.1 General

Swale design is based on open channel design – balancing storage, treatment and infiltration during small storms with the need for peak flow conveyance during larger events. The hydraulic and treatment design for swales is therefore integrally linked and design methods for both are covered together in this section.

The following should be accounted for when considering the hydraulic design of all swales:

1. The swale should have adequate capacity to convey and/or store the design return period event (component level of service). It should be noted that wet swales will tend not to recover so well from high flows, so a reduced level of service may be appropriate.
2. The swale should have the ability to safely convey extreme event flows, or else excess flows should be safely passed to appropriate temporary exceedance flow storage areas or conveyance paths.
3. The design event runoff volumes should half empty within 24 hours. This will help to ensure that storage and treatment volumes are available for subsequent events and, for dry/conveyance swales, should also protect vegetation from damage by saturated conditions.

1 Conveyance swales

Vegetation in the swale should typically be maintained at a height of 75–150 mm to prevent flattening during flow events (or suitable planting specified for a greater depth of flow).

Good pollutant removal performance is required for all runoff events up to and including events which occur, on average, about once a year (termed here the 1:1 year event). The duration of this event should be the relevant critical duration for the swale. If the swale is draining a road then 15 minutes is likely to be appropriate. For this water quality design event:

- the depth of flow should be maintained below the height of vegetation (ie usually < 100 mm)
- the maximum flow velocity in the swale for such an event should be 0.3 m/s to ensure adequate runoff filtration
- the time of travel of runoff along the swale (residence time = length/velocity) should be at least 9 minutes (18 minutes from the top of the swale, if the swale has lateral inflows along its length).

To calculate the average velocity of flow in a swale, Manning's equation should be used (**Section 24.11.1**). The Manning's "n" value, or the "roughness coefficient" indicates to what extent the surface of the swale will resist flow, and is critical in its sizing. The coefficient varies with the type of vegetative cover and the flow depth, and a suggested relationship between flow depth and Manning's "n" for grass channels is given in **Figure 17.7** with a value of 0.35 recommended for a depth of water below or equal to the height of the grass. This coefficient will need to be increased for swales that include larger plants and/or a greater range of plant sizes.

Flow velocities for extreme events should be kept below 1.0 m/s (or 2.0 m/s if slope stability, soil erosion and safety conditions allow) to prevent erosion. The average Manning's "n" value for above grass flows will need to be estimated, depending on the flow depth.

Check dams and appropriate pre-treatment systems can be used to improve both hydraulic and water quality performance of a swale system by reducing velocities, increasing residence time and increasing infiltration and/or storage (**Sections 17.8.1 and 17.9.2**).

Where swales are being designed for conveyance capacity in larger events, it is suggested that design criteria for these systems should not assume extra allowances for loss of volume. Where swales are to be designed to discharge significant volumes via infiltration, the systems should be designed as a form of soakaway or infiltration basin (**Chapter 13**).

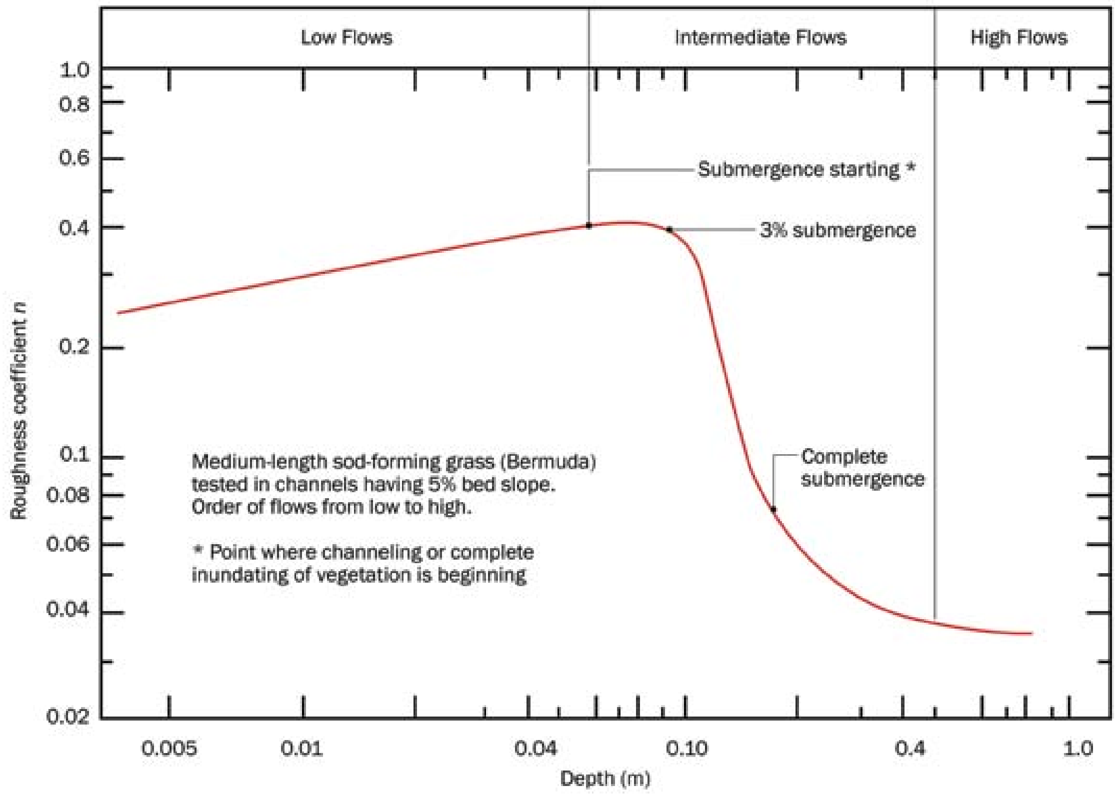

Figure 17.7 Impact of flow depth on hydraulic roughness (from Wong, 2006)

2 Dry swales

The enhanced drainage beneath the swale can provide increased flow and storage capacity, extra Interception performance, a reduced risk of localised ponding and marshy areas developing where gradients are flat, and improved conditions for infiltration (where ground conditions allow).

Dry swales that are served by an underdrain need not have an above-ground outfall (although this is usually required for exceedance flow management purposes) and can therefore act as a connected length of detention basins. Their performance is complex as the relative head in each swale serving the underdrain will define its hydraulic performance. An added uncertainty is that where the bedding around the underdrain has a relatively low permeability, the capacity of the underdrain itself may not be the limiting condition. Careful design of each element is needed to assess a system's performance to ensure that design events can be dealt with without downstream flooding.

Figure 17.8 Dry swale with overlying flow control, Upton, Northamptonshire (courtesy Peterborough City Council)

The velocity limits for regular and extreme events stated for conveyance swales are relevant here but as these systems are best suited to relatively flat areas or short lengths, the design constraint is normally its conveyance and storage performance, rather than velocity. The underdrain should usually have flow capacity of at least 2 l/s/ha to ensure that systems can deal with multi-event scenarios. If filtration into the underdrain will occur faster than the required limit of discharge, then a flow control on this element will be required.

3 Wet swales

The conveyance capacity of wet swales can be determined by using the same approach as for conveyance swales. The requirement to constrain velocities for the water quality treatment event to ensure suitable vegetative filtration will not normally be relevant, as the shallower (or zero gradient) longitudinal slopes associated with wet swales will ensure suitable retention times.

A permanently wet swale base can provide quiescent zones for the removal of fine particles – acting as small linear pond/wetland systems (**Chapter 23**). Wet swales are usually appropriate where sites are very flat and soils are poorly drained, but can be designed for more permeable sites using impermeable liners to deliver specific treatment performance or amenity or biodiversity requirements. Wet swales will occur naturally where high water tables rise above the swale base, but this provides a direct hydraulic link between runoff and groundwater and should not normally be allowed (**Chapter 4**).

Adequate pre-treatment should be included to avoid the rapid build-up of sediments in marshy wetland surfaces (which is more difficult and damaging to remove) and to ensure that any areas of permanent water do not receive contaminated runoff that could pose a risk to amenity and biodiversity performance of the system.

A minimum depth of water of 150 mm is usually appropriate to protect wetland vegetation from erosive flows and maintain adequate resilience of the system to drought. Maximum water depths should be set on a site-by-site basis, taking into account both technical, amenity (including safety) and biodiversity criteria. Appropriate depth ranges should follow the guidance given for ponds and wetlands (**Section 23.2**).

17.4.2 Interception design

Conveyance swales and dry/enhanced swales deliver Interception because there is usually no runoff from them for the majority of small rainfall events. The water soaks into the surface vegetated soil layers and into the underlying soils or other media, and is removed by evapotranspiration and infiltration (where allowed). The extent of the volumetric reduction in runoff will depend on the infiltration rate of the surrounding soil, the capacity of any underlying filter media, the catchment area, the area of the swale, the type of vegetation and the climate.

Where there is infiltration capacity, infiltration is acceptable and the swale is designed to facilitate even limited infiltration, then a simple infiltration design calculation will determine whether the swale is able to dispose of 5 mm rainfall depth over the contributing catchment area (**Section 25.6**).

Where there is no infiltration, but the natural surface soils (or imported or re-engineered soils) have water storage capacity, then Interception design should follow the principles set out in **Section 24.8**.

Interception cannot be assumed for wet swales, unless its delivery is explicitly demonstrated in the design.

17.4.3 Peak flow control design

Swales can help reduce flow rates from a site by facilitating infiltration and/or by providing attenuation storage. For swales, the peak flow control design and assessment of the surface storage volume can be determined by using standard hydraulic assessment. Infiltration contributions should only be included for dry or enhanced swales, where slopes are < 1.5% and where contributions to peak flow reductions are explicitly determined by the design. The design inflows should always include runoff from the pervious side slopes draining to the swale.

Further storage can be provided beneath the swale base using gravel or other filter/drainage medium or geocellular crate systems (**Chapter 21**), that is:

Available attenuation storage in the filter media and drainage layer of the swale system
= volume of system × void ratio in the soil/drainage layer

A flow control structure is generally required to constrain the rate of water discharged from the surface and/or subsurface system (**Chapter 28**).

17.4.4 Volume control design

Swales are not normally assumed to provide any reduction in volume of runoff for the 1:100 year, 6 hour event, but if infiltration rates from the system are deemed to be significant for this scale of event, then this should be explicitly accounted for by the design.

17.4.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the swale. This can be achieved by installing an overflow pipe or weir/overflow structure above the design water storage level to convey excess flows downstream. As swales tend to be long linear components, several overflows are likely to be required.

The exceedance flow capacity of the overflow(s) should be confirmed using standard hydraulic assessment methods and analysis (weir, orifice and pipe flow) (**Section 24.12**). Exceedance flows beyond the capacity of the overflow(s) should also be reviewed.

Any exceedance flow structure should be located as close to the swale inlet as possible to minimise the flow path length for above-capacity flows (thus reducing the risk of scouring). Vegetation in wet swales is likely to be especially vulnerable to damage from high flows. Alternatively, exceedance flows can be diverted past the swale using alternative flow routes.

17.5 TREATMENT DESIGN

Swales can help retain runoff from small events on site (ie deliver Interception – **Section 17.4.2**), helping reduce the contaminant load discharged to surface waters via volumetric control. They can also treat the residual runoff through the following methods.

Conveyance and dry swales

- Coarse to medium sediments and associated pollutants (such as nutrients, free oils/grease and metals) can be removed by filtration through surface vegetation and groundcover.
- Fine particulates and associated contaminants can be removed by infiltration through the underlying soil and/or filter medium layers. This provides treatment by filtration, dissolved pollutant removal by sorption of pollutants to the filter medium, and some biological uptake by vegetation and subsoil biota.
- Organic contaminants can be removed through photolysis and volatilisation.

Wet swales

- Fine particulates can be removed by adsorption and sedimentation.
- Nutrients and dissolved metals can be removed via biodegradation and plant uptake.

Design characteristics to deliver good pollutant removal performance are covered in **Section 17.4.1**, due to the link with hydraulic performance. In the past there have been recommendations that keeping grass short in swales prevents the grass lodging over (ie being pushed over and flattened by the flow of water) and improves pollution removal. However, the risk of pollution removal being compromised is now considered to be minimal, and there is no reason for a blanket requirement to keep grass short in all swales.

The acceptability of allowing infiltration from the swale will depend on the extent of the likely runoff contamination and site characteristics (see **Chapter 4, Table 4.3**).

Research has shown that the pollutant mass removal rates of grass swales are extremely variable, depending on influent pollutant concentrations (Bäckström *et al*, 2006), but are generally moderate for most pollutants (Barrett *et al*, 1998, Deletic and Fletcher, 2006). Median pollutant mass removal rates of swales from available performance studies have been reported as 76% for total suspended solids, 55% for total phosphorus and 50% for total nitrogen (Deletic and Fletcher, 2006). Significant reductions in total zinc and copper event mean concentrations have been observed in performance studies with a median value of 60%, but results have varied widely (Barrett, 2008). Site specific factors such as slope, soil type, infiltration rate, swale length and vegetative cover also affect pollutant mass removal rates. In general, the dominant pollutant removal mechanism operating in grass swales is infiltration, rather than filtration, because pollutants trapped on the surface of the swale by vegetation or check dams are not permanently bound (Bäckström *et al*, 2006). Evidence of the removal efficiencies of swales is presented in **Chapter 26, Annex 3**.

17.6 AMENITY DESIGN

Swales can be designed to fit into many different landscape types in an aesthetically pleasing manner, often delivering attractive vegetated corridors into streetscapes and road/parking corridors (**Figure 17.9**).

They should be aligned to avoid sharp bends, as these can cause erosion, but gradual meandering bends can be used for aesthetic purposes and to promote slower flows. The swale design should take account of the required orientation, aspect and proximity to other landscape features, buildings etc, and the swale should have an appropriate scale and form to suit the surrounding landscape character. In green open spaces they should have a natural feel with soft edges and flowing forms whereas some hard edges and straight lines may be appropriate in dense urban landscapes. The design should always aim to contribute to the amenity of the local communities.

Plant species should be selected to suit the existing landscape characteristics of the site and/or to meet its visual and design intent.

Small interpretation boards can be provided adjacent to the swale, potentially including information relating to the function of the swale and the local fauna and flora that the system supports (**Section 5.2.7**).

Lamb Drove (courtesy Peterborough City Council)

Upton

Figure 17.9 Examples of swales providing a vegetated corridor

Swales are generally shallow surface features that do not present significant risk or danger to the health and safety of the general public. Any residual risks can be mitigated through the design of shallow side slopes and shallow flow depths. If there is any chance of permanent depths of water occurring, wet swale designs should follow safety guidance given in **Chapters 23 and 36**.

In certain locations, some form of physical barrier may be appropriate to prevent vehicles parking on the swale edges (eg structural planting, bollards or low railings). Large rocks or boulders tend to lead to grass damage and scouring. Alternatively, the edge of the swale may be reinforced to prevent damage from vehicles.

17.7 BIODIVERSITY DESIGN

By following the biodiversity principles in **Chapter 6**, biodiversity value of any SuDS system can be maximised. Swales can include a variety of planting (including wildflower grass seed mixes in areas where the grass length is not required to be regularly maintained) that will help make a positive contribution to urban biodiversity – providing habitat and food for insects, invertebrates and birds.

Native plant species should normally be used in providing a dense and durable cover of vegetation that creates appropriate habitat for indigenous species.

Figure 17.10 School children in a shallow swale designed for play, Worcestershire (courtesy Robert Bray Associates)

17.8 PHYSICAL SPECIFICATIONS

17.8.1 Pre-treatment and inlets

Water should preferably be directed laterally into a swale (by draining runoff as sheet flow from the edge of a contributing impermeable area) rather than entering the swale as a single point inflow . This minimises erosion and disperses pollution widely in the surface vegetation. As an alternative, a series of drop kerbs at frequent intervals can be used. However, the transition from the kerb to the swale should ensure that the vegetation behind the kerb does not obstruct the flow of water to the swale. Where runoff is directed into swales by flow-concentrating devices such as gullies or pipes, the risk of erosion and silting is increased. This should be mitigated by constructing inlets with flow spreaders and erosion control, together with appropriate pre-treatment. Also the catchment area draining to any single inlet should be minimised.

Figure 17.11 Linear wet swale, Junction 4 M8, West Lothian

Where swales are located next to roads, a lateral gravel-filled drain may be provided at the edge of the pavement construction in order to prevent water seeping into the pavement layers and subgrade and affecting the structural strength of the road.

Shallow side slopes or vegetated filter strips at the edge of the impervious surface are useful as a pre-treatment system for runoff entering swales and will improve the water quality performance of the system. There should be a drop of at least 50 mm from the pavement (or hard surface) edge to any vegetated surface to prevent the formation of a sediment lip.

▶ Inlet structures are discussed in detail in **Chapter 28**.

17.8.2 Underdrains and outlets

Underdrains should use PVC perforated pipe (minimum diameter usually 100 mm) with 150 mm clean gravel above the pipe. The gravel and pipe should be enclosed by geotextile fabric. The underdrain should infiltrate into the subsoils or drain freely to an acceptable discharge point.

▶ Detailed underdrain design guidance is set out in **Section 18.8.2**.

An outlet pipe has to be provided from the swale channel (for conveyance swales) and/or underdrain systems (for dry/enhanced swales) to the point of discharge. Outlet erosion protection may be required. An overflow structure and non-erosive overflow channel should be provided to safely pass flows in excess of the swale storage capacity to the downstream drainage system.

Inspection pipes should be provided to underdrains to provide access for performance observations and cleaning.

▶ Outlet structures are discussed in detail in **Chapter 28**.

17.9 MATERIALS

17.9.1 Filter media and underdrain

▶ Guidance for the specification of materials for any underlying filter media and underdrains are set out in **Section 18.9**.

17.9.2 Check dams

Where required, check dams are typically provided at 10–20 m intervals and the water level at the toe of the upstream dam should be the same level as the crest of the downstream dam (**Figure 17.13**). Check dams may be constructed from coarse aggregate (100–600 mm, eg Class 6B material as specified in DfT, 1998), wooden boards, gabions or earth (if adequately protected against erosion), rip-rap or concrete (where appropriate). Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.

Energy dissipation and erosion protection materials should extend 1–2 m downstream of the dam across both the base and sides of the swale, if required. Check dams should be constructed into the sides of the swale to ensure that water does not bypass the structure and a small orifice or pipe at the base of the dam will allow low flows to be conveyed downstream. Risks of orifice blockage should always be considered. Interconnections should be designed so that flow does not resuspend settled material or cause local erosion, and so that floating solids and surface films are retained. **Figures 17.14 and 17.15** show examples of granular and timber check dams, respectively. **Figure 17.12** shows how check dams can be designed to complement the local landscape.

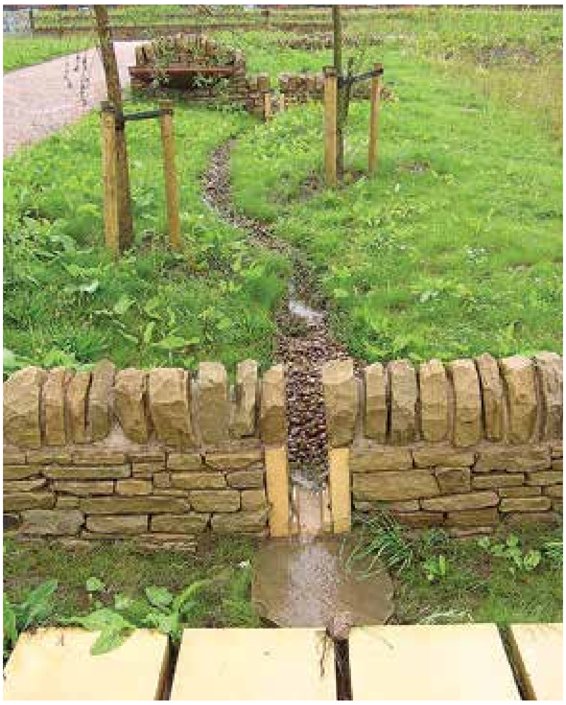

Figure 17.12 Check dam wall using local materials, Sheffield (courtesy Sheffield City Council)

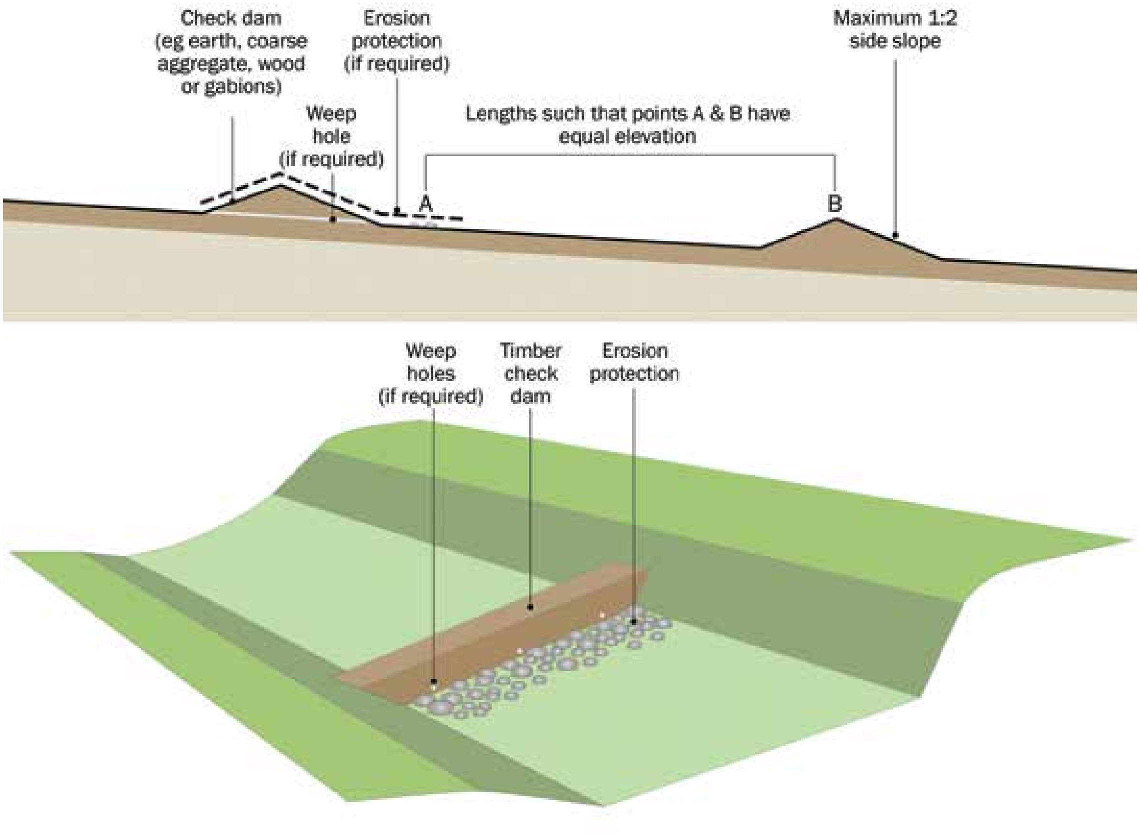

Figure 17.13 Typical check dam details

Figure 17.14 Roadside swale with granular check dams (courtesy Oxfordshire County Council)

Figure 17.15 Timber check dams, Rednock School, Gloucestershire (courtesy Illman Young)

The impact of check dams on maintenance activities should be evaluated by the designer.

17.9.3 Gravel flow spreader

Gravel flow spreaders should comprise washed stone of 3–10 mm in diameter. The diaphragm should be at least 300 mm wide and 600 mm deep.

17.9.4 Flow dividers

Flow dividers (if required) should be constructed of a firm material that will resist weathering and erosion, such as concrete, recycled plastic or a compacted soil berm seeded with the swale vegetation. Materials used for this purpose must not leach chemicals into the swale. If erosion is likely to be a problem, then erosion control fabrics, coir blankets or geotextiles can be used.

17.10 LANDSCAPE DESIGN AND PLANTING

Grasses and herbaceous species with a soil-binding root structure and dense cover should be favoured along the bottom of the swale for their ability to increase infiltration, stabilise soils, retain and filter pollutants and assist with suspended solids retention. Where swales are used to drain runoff from roads or car park areas that are likely to be regularly salted during winter months, the planting should be salt tolerant.

The plant material on the slopes of grass channels should be capable of withstanding periodic inundation in addition to extended periods of drought. Appropriate species include robust, fine-growing grasses and groundcovers as well as low shrub species. Native species are generally most appropriate, and mixtures of perennial ryegrass and fescues are particularly suitable for use in swales in the UK. Longer grasses and wildflower areas, if considered beneficial for other reasons, are not considered to pose a significant risk to performance.

Trees can be included within a design, provided that the required sun-shade conditions needed for adequate growth of the predominant groundcover vegetation are fully considered. The requirements for topsoil depths and specifications will vary, depending on the design planting.

Fertilising a swale should be avoided if possible, particularly where the receiving environment is sensitive to nutrient loadings.

Emergent vegetation can be planted in wet swales or, alternatively, wetland soils may be spread on the swale bottom for seed stock. However, dense planting should be avoided, and systems should be allowed to colonise naturally to an extent. For wet swales, it is best to plant several species to increase the chance that at least some of the selected species will find growing conditions favourable.

For dry swales, plants can be placed as turf, seeds or less commonly as individual plants, such as plug plants or rooted specimens. Turf provides immediate protection, provided the seams are protected by laying the strips perpendicular to the flow of water and hand tamping them after laying. Turf should also be secured with pegs where high flow velocities are expected and on side slopes that are greater than 1 in 4. A swale is best seeded during spring and early summer months to give vegetation the whole length of a growing season to establish. Grasses will need to be maintained at lengths of 75–150 mm to ensure performance during regular events.

▶ Landscape design and planting best practice is presented in detail in **Chapter 29**.

17.11 CONSTRUCTION REQUIREMENTS

Grass swales should be clearly marked before site work begins and protected by signage and silt fencing to avoid their disturbance during construction. No vehicular traffic, except that specifically used to construct the component, should be allowed close to the swale. Excavating equipment should operate from the side of the swale and not the base. If compaction of soils does occur, a minimum of 300 mm depth of soil should be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth.

Care should be taken that design levels and slopes for inlets and swale base and sides are constructed accurately to avoid runoff bypassing swale inlets, ponding in the swale base and flow channelling. Even the smallest non-conformities may compromise flow conditions.

Swales should not receive any runoff until the vegetation is fully established and construction at the site has reached a state where sediment loads will not cause rapid siltation of the swale. This can be achieved by:

- diverting flows until the vegetation is well rooted
- placing an erosion control blanket (eg jute, straw or geosynthetic mats) over the freshly applied seed mix
- using bare earth as a temporary cover during the wet season – these areas should be seeded with a suitable grass mix as soon as the weather is conducive to seed germination.

If sediment from construction work accumulates on a swale it should be cleared and the swale fully rehabilitated before the drainage system is adopted by the organisation carrying out the maintenance.

The swale should be planted at a time of year when successful plant establishment without irrigation is most likely (noting that temporary irrigation may still be required if the period is especially dry). Freshly seeded areas should be stabilised with appropriate temporary or permanent soil stabilisation methods, such as erosion control matting or blankets. If more than 30% of the planted area is bare after four weeks, reseeding or replanting should be considered to achieve 90% coverage.

Figure 17.16 Swale during construction showing coir matting used to protect soils from erosion before the establishment of vegetation, University of York (courtesy Arup)

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety guidance is provided in **Chapter 36**.

17.12 OPERATION AND MAINTENANCE REQUIREMENTS

Swales will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of swales is dependent on maintenance, and robust management plans will be required to ensure maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance.

Maintenance of swales is relatively straightforward for landscape contractors, and typically there should only be a small amount of extra work (if any) required for a swale over and above what is necessary for standard public open space. Provided that landscape management is already required at site, swale maintenance should have marginal cost implications. However, regular inspection and maintenance are important for the effective operation of swales as designed. Maintenance responsibility for a swale should always be placed with an appropriate organisation. If swales are implemented within private property, owners should be educated on their routine maintenance needs, and should understand the long-term Maintenance Plan and any legally binding maintenance agreement.

Adequate access should be provided to all swale areas for inspection and maintenance, including for appropriate equipment and vehicles. Litter and debris removal should be undertaken as part of general landscape maintenance for the site and before any other SuDS management task. All litter should be removed from site.

The major maintenance requirement for dry swales is mowing. Mowing should ideally retain grass lengths of 75–150 mm across the main “treatment” surface, to assist in filtering pollutants and retaining sediments and to reduce the risk of flattening during runoff events. However, longer vegetation lengths, where appropriate, are not considered to pose a significant risk to functionality.

Figure 17.17 Grass cutting of roadside swale, Stirlingshire (courtesy Abertay University)

Grass clippings should be disposed of either off site or outside the area of the swale, to remove nutrients and pollutants. For wet swales, mowing of wetland vegetation is not required. However, harvesting of very dense vegetation may be desirable in the autumn after plant die-back, to prevent the discharge of excess organic material into receiving waters. All vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Occasionally sediment will need to be removed (eg once deposits exceed 25 mm in depth), although this can be minimised by ensuring that upstream areas are stabilised and by incorporating effective pre-treatment devices. Available evidence from monitoring studies indicates that small distributed infiltration practices such as swales do not contaminate underlying soils, even after more than 10 years of operation (TRCA, 2008). Sediments excavated from a swale that receives runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For runoff from busy streets with high vehicle traffic, sediment testing will be essential. Any damage due to sediment removal or erosion should be repaired and immediately reseeded or planted.

▶ Further detail on waste management is provided in **Chapter 33**.

Table 17.1 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the swales should be monitored, and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is provided in **Chapter 36**.

TABLE 17.1 Operation and maintenance requirements for swales

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly, or as required
	Cut grass – to retain grass height within specified design range	Monthly (during growing season), or as required
	Manage other vegetation and remove nuisance plants	Monthly at start, then as required
	Inspect inlets, outlets and overflows for blockages, and clear if required	Monthly
	Inspect infiltration surfaces for ponding, compaction, silt accumulation, record areas where water is ponding for > 48 hours	Monthly, or when required
	Inspect vegetation coverage	Monthly for 6 months, quarterly for 2 years, then half yearly
	Inspect inlets and facility surface for silt accumulation, establish appropriate silt removal frequencies	Half yearly
Occasional maintenance	Reseed areas of poor vegetation growth, alter plant types to better suit conditions, if required	As required or if bare soil is exposed over 10% or more of the swale treatment area
Remedial actions	Repair erosion or other damage by re-turfing or reseeding	As required
	Relevel uneven surfaces and reinstate design levels	As required
	Scarify and spike topsoil layer to improve infiltration performance, break up silt deposits and prevent compaction of the soil surface	As required
	Remove build-up of sediment on upstream gravel trench, flow spreader or at top of filter strip	As required
	Remove and dispose of oils or petrol residues using safe standard practices	As required

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Image courtesy Kent County Council

18 BIORETENTION SYSTEMS

Contents

Chapter 18 Bioretention systems

This chapter provides guidance on the design of bioretention systems (including rain gardens) – shallow planted depressions that allow runoff to pond temporarily on the surface, before filtering through vegetation and underlying soils for collection or infiltration.

▶ *Appendix C, Section C.5.2 demonstrates how to design an infiltrating bioretention system for a civic street.*

18.1 GENERAL DESCRIPTION

Bioretention systems (including rain gardens) are shallow landscaped depressions that can reduce runoff rates and volumes, and treat pollution through the use of engineered soils and vegetation. They are particularly effective in delivering Interception and can also provide:

- attractive landscape features that are self-irrigating and fertilising
- habitat and biodiversity
- cooling of the local microclimate due to evapotranspiration.

They are a very flexible surface water management component that can be integrated into a wide variety of development landscapes using different shapes, materials, planting and dimensions. In a low density development, the system might have soft edges and gentle side slopes, while a high density application might have hard edges with vertical sides.

They are generally used for managing and treating runoff from frequent rainfall events. Where larger events are directed to the system, consideration of the impact of design velocities on the system will be required. It is often more appropriate to pass runoff from extreme events directly to drainage components further downstream, via an overflow or bypass.

Runoff collected by the system ponds temporarily on the surface and then filters through the vegetation and underlying soils. Specified engineered soil mixes can be used as filter media to enhance bioretention treatment performance, and designs can be implemented that include submerged anaerobic zones to promote nutrient removal.

The filtered runoff is either collected using an underdrain system or, if site conditions allow, fully or partially infiltrated into the surrounding soil (subject to suitable site conditions – **Chapter 25**). Part of the runoff volume will be removed through evaporation and plant transpiration. The main hydraulic benefit of using bioretention systems is providing Interception. However, attenuation storage on the surface or within the drainage layer can be used to help manage runoff rates. Check dams or weirs can also be used to slow the flow of water moving across the surface of the system.

There are many different approaches to the design of bioretention systems and rain gardens. However, the main components that are usually provided in a bioretention system are shown in **Figure 18.1** In general, the systems should not have impermeable liners, unless there is a specific need to prevent water from infiltrating, such as at locations close to structural foundations (**Chapter 25**) or for groundwater protection (**Chapter 26**).

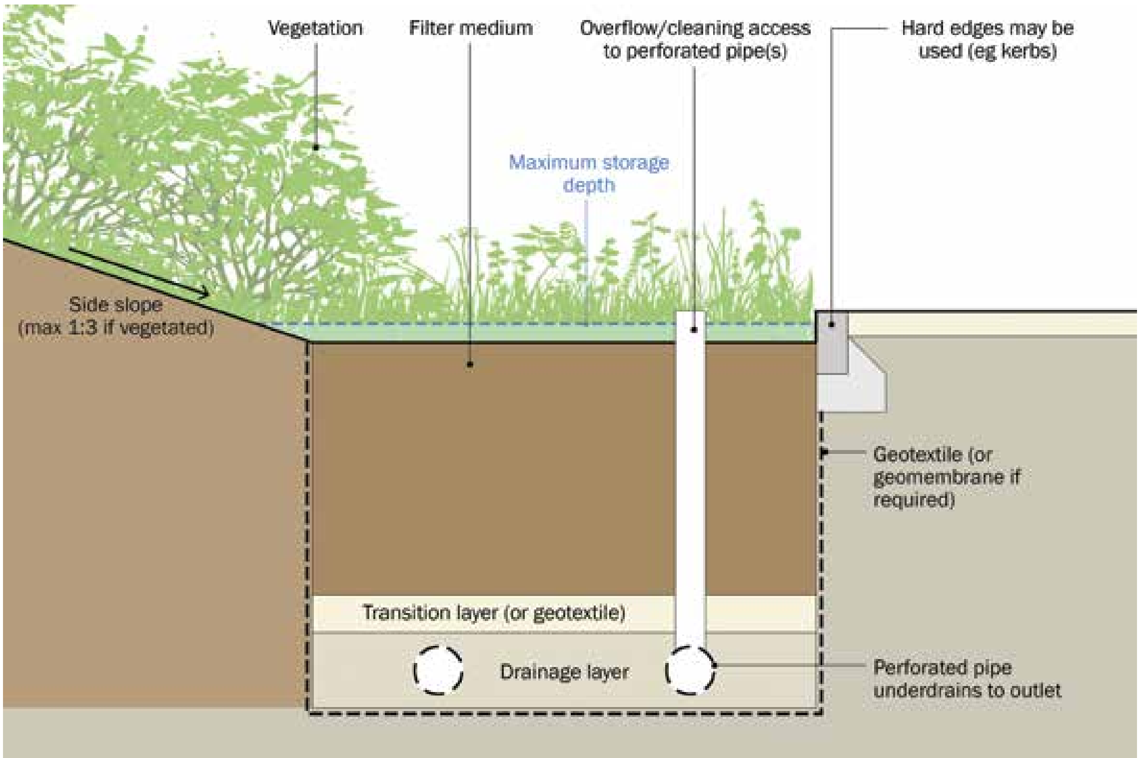

Figure 18.1 Components of a bioretention system

The main functions of the different elements of the system are as follows:

Inlet – The inlet design is critical and should be designed to prevent scour and erosion and to evenly distribute water onto the filter surface (**Section 18.8.1**).

Depth of extended detention – This is temporary storage of water on the surface to capture the volume that requires treatment and (if required) provide attenuation. Normally this will be at a maximum depth of 150–300 mm.

Vegetation – Vegetation influences the performance of the system through direct uptake of pollutants and by facilitating physical and chemical processes in the soil that remove nutrients. It also prevents erosion of the surface soil layers and helps maintain the permeability of the filter medium. Vegetation can have a strong influence on the amenity and biodiversity value of the system. Vegetation selection is very site specific and requires the input of landscape architects, ecologists or horticultural or arboricultural experts.

Filter medium – This material is normally sand-based with some source of organic matter and slow-release plant nutrients to maintain healthy plant growth. It filters out pollutants and controls the rate at which water filters through the system, which is a key influence on the effectiveness. It is normally 750–1000 mm deep, although for very small catchments it can be less than this (eg where a raised planter is draining only a small area of roof). An absolute minimum of 400 mm is recommended, and in such situations the system should only contain ground cover plants. Proprietary filter media that have enhanced performance may be used to reduce the area and depth of filter medium required.

Transition layer – This is required to prevent the washing of fines from the filter medium into the drainage layer. To achieve this it should be at least 100 mm deep and should be designed using standard geotechnical filter criteria (**Chapter 30**). Alternatively a geotextile layer can be used, which again should be designed using standard filter criteria. There have been instances of geotextile layers clogging in bioretention systems and some publications (eg the Facility for Advanced Water Biofiltration (FAWB), 2008) recommend that they are not used. However, appropriate specification of the pore size and permeability of the geotextile in relation to the soils above it should reduce the risk of this occurring and the risk should not be any different from that for clogging of a transition layer (**Chapter 30**). The main location where silt accumulates in a bioretention system is on the surface of the soil filter.

Drainage layer – The purpose of this layer is to collect water from the filter medium and allow it to reach the perforated pipes easily. The drainage layer should provide adequate cover to the perforated pipes (typically at least 100 mm) and should be of sufficient thickness to ensure that the flow rate of water through it to the pipes is greater than the flow rate of water into the layer from the overlying filter medium and/or transition layer. Geocellular units can also be used in place of the drainage layer and pipes, especially if extra attenuation storage volume is required.

The depth of the drainage layer will be determined by the underdrain pipe diameter, minimum pipe cover, the level of the outfall/connection, slope of the underdrain and the length of the system being drained, and any requirements for storage. In general, the minimum pipe cover of the gravel drainage layer should be 50 mm to avoid ingress of the sand transition layer into the pipe. Where the drainage layer is acting as a storage layer, the depth should be determined using calculations or modelling but as a general guide the subsurface storage zone should be at least as large as the surface storage zone to ensure that the filter medium does not become saturated after consecutive rainfall events.

Perforated pipes – These collect water from the system and convey it downstream. They may not be required if the system is designed to infiltrate. Pipes should have a rodding eye, to allow access for cleaning (this could be combined with the overflow).

Overflow – This is achieved with standpipes, weirs or other channel to direct flow to downstream components, once the volume of the system has been exceeded.

There are many different variations of the bioretention system, described in the following sections.

18.1.1 Rain garden

Rain gardens are typically small systems that serve part of a single property (roof or driveway). They are likely to be less engineered than full bioretention components. In simple rain gardens, filter and drainage layers are generally replaced by a thin (200–500 mm) layer of compost/sand-amended native soils or specified soil mixes (engineered soils). They usually have a simple inflow where rainwater enters the garden and they have a maximum depth of standing water of 150 mm. They can have an above-ground overflow where excess water exits, although in some instances a simple underdrain may be more effective than providing a small control structure (**Figure 18.2**). Guidance on simple rain gardens is provided in Bray *et al* (2012).

Rain gardens can offer a variety of creative design interpretations to suit the site. In **Figure 18.3** the size and design of the rain gardens were chosen by the property owners to provide a distinctive feature in their gardens.

There needs to be a mechanism to ensure that property owners carry out the necessary maintenance of rain gardens so that they continue to perform their drainage function effectively.

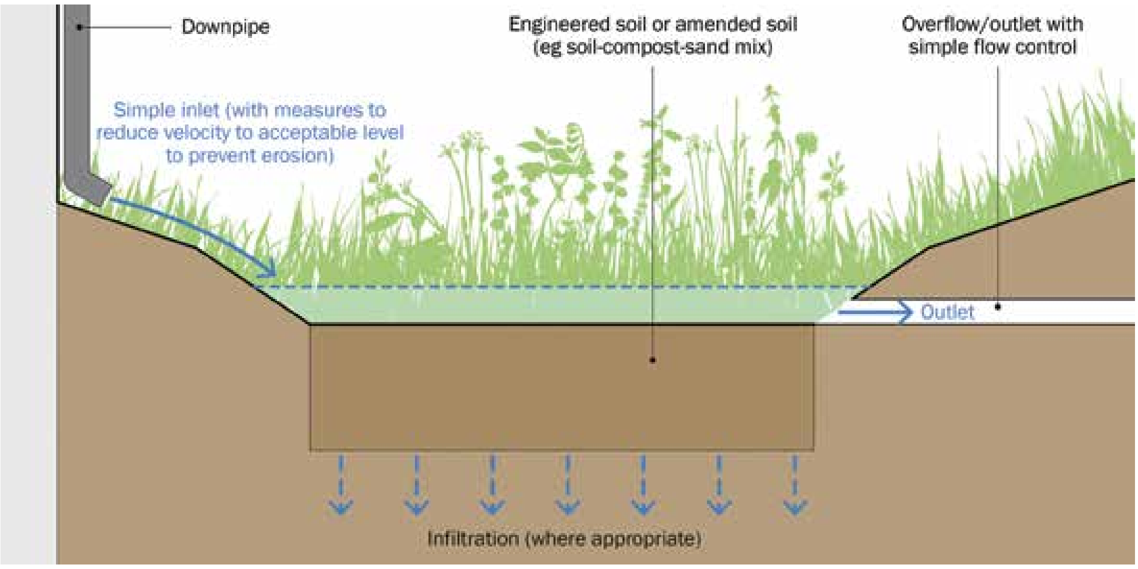

Figure 18.2 Section through a simple rain garden with outlet pipe

Figure 18.3 Examples of rain gardens under construction and planted, Cheltenham (courtesy EPG Limited and Illman Young)

Figure 18.4 Raised planter at Hollickwood School, London (courtesy WWT)

18.1.2 Raised planter

These are boxed systems (that can be prefabricated) constructed above the surrounding ground surface, with a planted soil mix and an underdrain to collect the filtered water. They are often used to manage runoff from adjacent roofs, and this type of system is useful for retrofitting in urban situations. Raised planters are not normally used as infiltration systems (**Figures 18.4 and 18.5**).

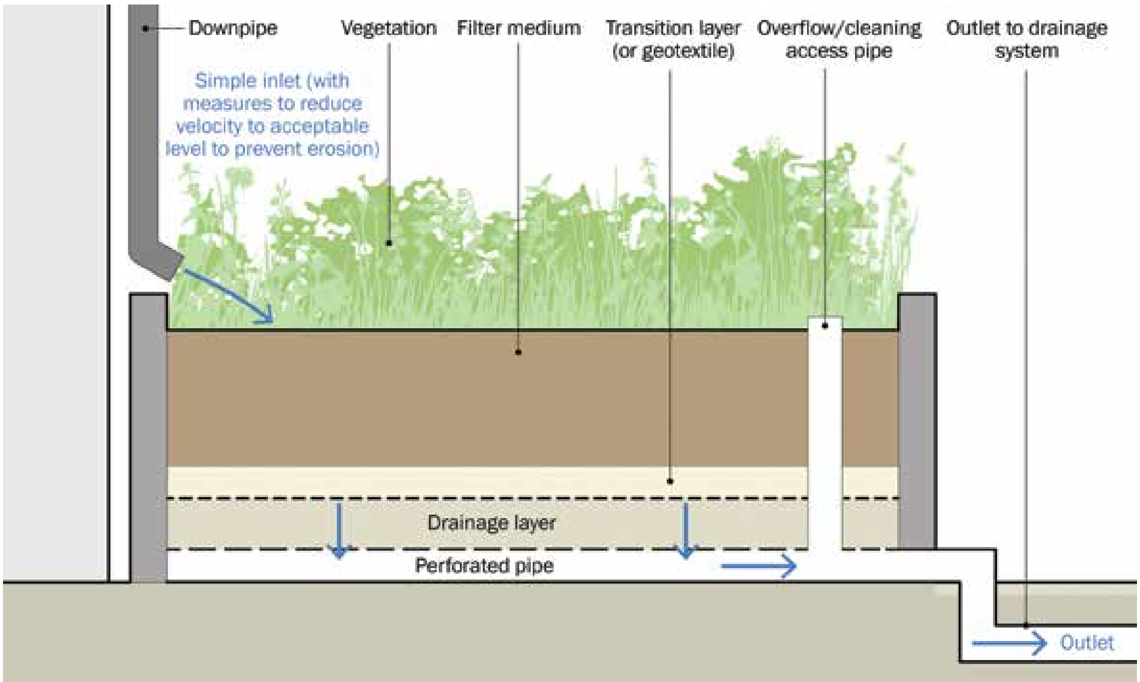

Figure 18.5 Section through a raised planter

18.1.3 Bioretention tree pit

These are tree pits (see **Chapter 19** for guidance on design) with enhanced performance achieved through extra surface planting (**Figure 18.6**). Trees and large shrubs are beneficial in bioretention systems as they:

- intercept precipitation and allow water to evaporate from leaf surfaces
- dissipate rainfall-runoff energy
- facilitate infiltration and groundwater recharge, because of their more extensive root systems
- provide shade and can reduce runoff temperatures
- provide further amenity and biodiversity benefits.

Figure 18.6 Bioretention tree pits, Portland, Oregon (courtesy Illman Young)

18.1.4 Bioretention swale (or trench)

These are bioretention systems that are located within the base of a swale (often referred to as bioswales in the USA) (**Figure 18.7**). They may involve a continuous component of bioretention along the length of the swale, or a portion of bioretention before the outlet of the swale. They are similar to an underdrained swale (see **Chapter 17**). Flows up to the treatment design event (ie from a 1:1 year event or less) soak into the filter and are collected by an underdrain. During events that exceed 1:1 year water will flow along the swale. The flow velocity and vegetation should be designed so that when water flows along the bioretention swale the filter material is not eroded. To achieve effective biofiltration, the base of the swale has to be constructed as a series of flat areas that are terraced down the length of the swale.

The vegetation used in the system should be tolerant of the likely inundation and flows that occur in this type of system.

Figure 18.7 Bioretention swale (courtesy Derwent Estuary)

18.1.5 Anaerobic bioretention system

The anaerobic bioretention system has the outlet pipe designed so that there is a permanent water level within the drainage layer. The water storage allows the vegetation to access it during dry periods and it assists with treatment of some pollutants (eg nitrogen). This type of system is particularly good where trees are planted, as the roots can readily access the stored water. If the submerged zone also contains a carbon source (eg hardwood chips at around 5% by volume) then this has been shown to further improve nitrate and heavy metal removal (FAWB, 2008).

Figure 18.8 shows a typical anaerobic bioretention system. If the permeability of the surrounding soil is too high (> 1×10^{-7} m/s) an impermeable liner may be required to hold water in the system and maintain the standing water level. It is important that the standing water level does not cause waterlogging of the soils above in which plants/trees are rooted and the depths of the overlying soil and level of the outfall should be designed to ensure this does not occur.

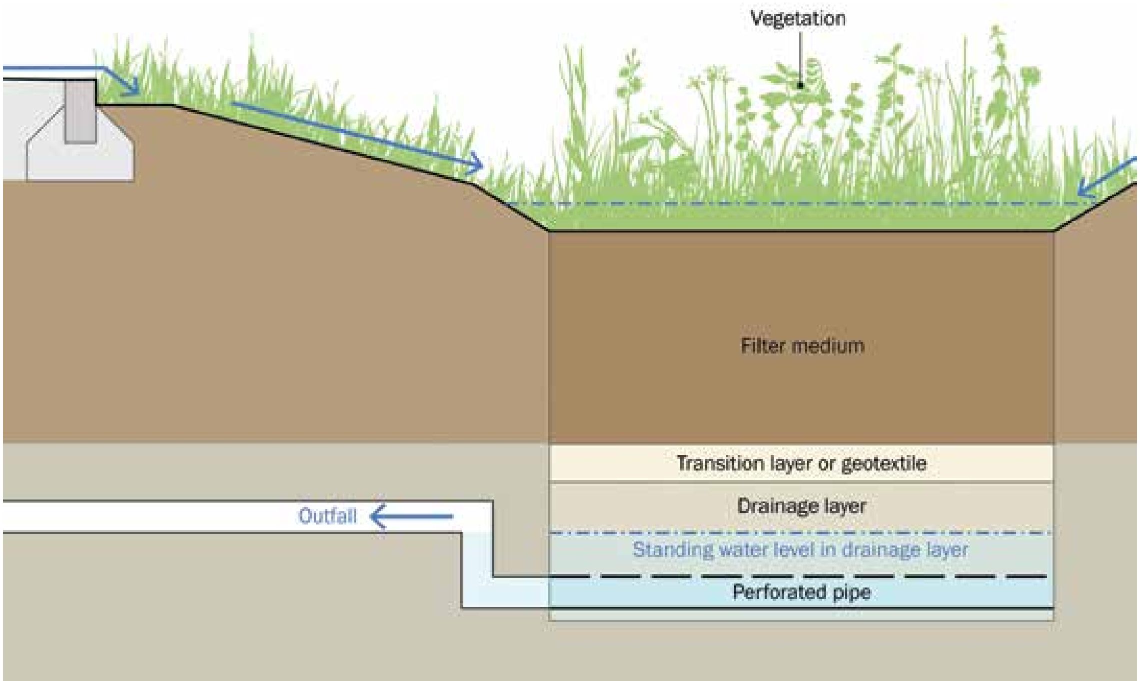

Figure 18.8 Anaerobic bioretention system

18.2 GENERAL DESIGN CONSIDERATIONS

Bioretention systems can be designed to manage a wide range of rainfall events, the limiting factors being the size of the catchment and the available space for the system. However, as a general principle, the systems should drain relatively small areas close to the source of runoff. They will not work effectively if designed to drain large catchments that discharge into the system at a single location without flow control. For larger catchments, a series of cascading systems could be considered. Smaller rainfall events may be filtered via the system, and larger rainfall events may bypass the system via an overflow.

Bioretention areas are generally applied to small catchments and the maximum recommended area that should drain to a bioretention system is 0.8 ha (Davis, 2008).

Likely inflow velocities should always be considered and suitable flow distribution and erosion protection measures put in place that are appropriate to the likely inlet flow velocity. Larger sites can be divided into several smaller parcels with multiple and/or linked bioretention zones.

Typically the surface area of the bioretention system should be 2–4% of the overall site area to be drained (FAWB, 2009) to prevent rapid clogging of the bioretention surface.

Bioretention areas are designed for intermittent flow and the surface should be designed to drain and re-aerate between rainfall events. This prevents the growth of moss, algae and biofilms which can clog the surface.

Bioretention areas can be used in most ground conditions. The surface of a bioretention system should be level to allow distribution of flows across it. They are, therefore, slightly more difficult to incorporate effectively within steeper catchments where they may require some form of small retaining structure or earth embankment to achieve this. However, rain gardens have been effectively used in sloping sites (**Figure 18.9**). The height of the retaining structures should be small to minimise health and safety risks (kerb height or similar). If drops greater than kerb height are proposed it may be appropriate to place a wall, hedge, or fence around the edges.

Where the underlying groundwater is not adequately protected from potential pollution risks, infiltration from contaminated surface runoff should be prevented, and the systems should be designed with an impermeable geomembrane liner and a positive connection to the main site drainage. Where a liner is

Cheltenham (courtesy EPG Limited and Illman Young) Portland (courtesy Illman Young)

Figure 18.9 Partially raised rain gardens on sloping sites

used to prevent infiltration, the seasonally high groundwater level should be below the level of the liner. If infiltration is allowed, the maximum likely groundwater level should be at least 1 m below the base of the system (**Chapter 25**).

Bioretention systems can be used to provide treatment of water before its use in harvesting systems (note that disinfection of the discharge from the feature will still be required where treatment of pathogens is critical). Solar-powered pumps have been used for this purpose where the water is used for irrigation. However, it should be recognised that these systems do tend to reduce volumes of runoff, thus reducing the available yield. Lined systems vegetated with small plants such as ornamental grass can be used to minimise evapotranspiration losses.

Systems with an underdrain should have cleaning access to the drain (for smaller systems this could be via the overflow to the drain).

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

18.3 SELECTION AND SITING OF BIORETENTION SYSTEMS

Bioretention systems are applicable to most types of development, and can be used in both residential and non-residential areas to mitigate polluted runoff from roads. They can be implemented in private curtilage for managing runoff from single properties, in small shared public areas, on car park islands, roundabouts, footpaths, traffic calming and pedestrian zones (streetscapes). Bioretention systems can be used to buffer structures, enhance privacy, and for aesthetic site features. Linear bioretention systems can be placed along roads, central reservations and build-outs, and help control flooding of the carriageway.

They are often a cost-effective retrofit option, due to their flexibility in size and detailing. They can be integrated within existing landscaped areas, within traffic islands or underused parking or road space when street works are planned for other reasons.

Bioretention systems should be incorporated into the site landscaping such that they do not require extra land-take over and above the landscaping that would normally be required for the development. The width of the system should be greater than 600 mm (less than this is difficult to construct) and less than 20 m (so it can be maintained using a 10 m reach excavator with access to both sides). If access is only available from one side, the maximum width should be 10 m. The maximum length should be 40 m to avoid uneven distribution of water over the surface, and the total filter area should not exceed 800 m^2. In practice, most examples that have been installed around the world are much smaller than these maximum dimensions and are integrated into the landscape as small local features.

Greater thicknesses of filter medium and a saturated drainage layer (anaerobic bioretention system – **Section 18.1**) are more appropriate where trees will be planted in the system and also if the vegetation proposed is less tolerant of drought. The larger the surface area of the system the more valuable a permanent body of water is, because it allows water to be evenly distributed below the whole of the filter medium and provides better irrigation for the plants that are remote from the inlet.

The acceptability of infiltration from the base of a bioretention system should be determined by following the guidance provided in **Section 25.2**, complying with all relevant requirements for infiltration systems with respect to ground stability, depth to water table etc, and **Section 26.7**, with respect to the protection of groundwater.

Building control departments may require unlined rain gardens to be located greater than 5 m from building foundations. If rain gardens are located closer than 5 m, a full assessment of the risks should be carried out by a suitably qualified geotechnical engineer or engineering geologist. If a rain garden manages water from a small area (< 20 m^2) is less than 300 mm deep, has a surface area greater than 2 m^2 and is greater than 3 m from foundations, such an assessment may not be necessary except for sites where there is contamination, steep slopes nearby or a history of instability such as sink holes. The local building control department will be able to provide advice.

18.4 HYDRAULIC DESIGN

18.4.1 General

A key hydraulic design consideration for bioretention systems is the delivery of the runoff onto the surface of the filter medium. Flow should not scour the bioretention surface and needs to be uniformly distributed over the full filter medium surface area. Inflow velocities should be below 0.5 m/s (or 1.5 m/s for the 1:100 year rainfall event).

When a bioretention system runs along the full length of a conveyance swale, the bed should be level in a series of terraces. For other applications, the desirable gradient of the bioretention zone is either horizontal or as close as possible to horizontal to encourage uniform distribution of runoff over the full surface area of the bioretention filter medium and to allow efficient temporary storage of flows for treatment before bypass occurs.

In steeper areas, where a bioretention system is used at the end of swale, check dams can be implemented along the system to reduce flow velocities discharged onto the bioretention filter medium. A check dam is a simple structure or mechanism that can consist of anything from an area on an existing slope where water can temporarily pond before proceeding further, to a small weir device that ponds water and spreads its flow. It should be noted that check dams should be designed to allow easy maintenance of grass, or other vegetation may be appropriate in these areas.

More frequent storm events are treated as water filters through the system and those that exceed the design treatment volume of water bypass the treatment system via an overflow. The design approach for bioretention systems is generally based on providing the following:

- sufficient surface area and depth to contain the required treatment volume and allow infiltration to the filter medium between storm events (normally 150–300 mm)
- an adequate hydraulic residence (filtration) time through the system to enable sediments and attached pollutants to be retained by selection of suitable planting/filter media
- extra storage in the drainage layer below the filter medium if required for attenuation.

Selection of an appropriate bioretention filter medium is a key design step involving consideration of three interrelated factors:

- the saturated hydraulic conductivity (permeability) required to optimise the treatment performance of the bioretention component given site constraints on available filter medium area

- the depth of extended detention provided above the filter medium
- the suitability of the medium to support vegetation growth (ie retaining sufficient soil moisture and organic content)

The permeability of generic soil filter media should be between 100–300 mm/h (see **Box 18.1** for example filter media specification). However, to allow for initial clogging rates (which tend to repair as the plant community establishes itself and the rooting depth increases), the design should be based on 50% of the measured hydraulic conductivity of the compacted medium. Proprietary filter media may achieve acceptable performance with permeability values outside this range, which should be verified by independent test results.

Good pollutant removal performance is required for all runoff events up to and including events that occur, on average, about once a year (termed here the 1:1 year event). The duration of this event should be the relevant critical duration for the bioretention system. For this water quality design event, bioretention systems should be designed so that they provide sufficient area to temporarily store the required treatment volume as a layer of not more than 150–200 mm depth on the surface. This will enhance evaporation and should limit the amount of time water is standing on the surface of the facility so that plants do not become waterlogged. It is recommended that a bioretention system should de-water within 24–48 hours of a design storm occurring. This, together with the specified permeability limits for the filter medium, should provide sufficient contact time to remove pollutants but ensure that the system is ready to receive subsequent events. It may be possible to allow a greater depth of water to attenuate more extreme events (eg up to 500 mm) if appropriate considering the landscape and safety context.

The surface area required to achieve this can be calculated by using **Equation 18.1**.

EQ. 18.1 Calculating required bioretention surface area

$$A_f = \frac{V_t\, L}{k(h + L)t}$$

where:

A_f = surface area of filter bed (m^2)

V_t = volume of water to be treated (m^3) (for a 1:1 year critical duration rainfall event)

L = filter bed depth (m)

k = coefficient of permeability of filter media for water (m/s)

h = average height of water above filter bed (half maximum height) (m)

t = time required for water quality treatment volume to percolate through filter bed (s)

For design purposes, the surface area and filter bed depth are normally chosen, and the equation rearranged to calculate the time required for the volume of water to pass through the system. This should be 24–48 hours. Note that an overflow or exceedance flow route is required for events that exceed the capacity of the system.

Where the systems are designed as infiltration systems, the filter medium permeability will dictate the rate at which infiltration from the system occurs (where this is lower than the infiltration capacity of the surrounding soils). Where the filter medium has conductivities of one to two orders of magnitude (ie 10 to 100 times) greater than that of the local soils, the preferred flow path for runoff will be vertically through the filter medium and into underdrains at the base of the filter medium. However, if the selected saturated filter medium hydraulic conductivity is less than 10 times that of the local soils, then impermeable liners may be required to prevent infiltration. It may also be necessary to provide an impermeable liner to the sides of the filter medium to prevent horizontal exfiltration and subsequent short-circuiting of the treatment provided by the bioretention system.

18.4.2 Interception design

Bioretention systems deliver Interception because there is no runoff from them for the majority of small rainfall events. The water soaks into the filter medium and is removed by evapotranspiration and infiltration (where allowed). The extent of the volumetric reduction in runoff will depend on the infiltration rate of the surrounding soil, the catchment area, area and depth of the system, type of vegetation and the climate.

▶ Interception design should follow the guidance provided in **Section 24.8**.

18.4.3 Peak flow control design

Bioretention systems can help reduce flow rates from a site by providing some attenuation storage and can reduce storage volume requirements where infiltration occurs. For bioretention systems and rain gardens the peak flow control design and assessment of the surface storage volume can be determined using standard hydraulic assessment and treating the surface of the system as an infiltration basin. The permeability of the filter medium should be used as the infiltration rate.

Subsurface storage can be provided by the void space in the filter medium and/or drainage layer in the system:

Available attenuation storage in the filter medium and drainage layer of the bioretention system = Volume of system × porosity in the soil/drainage layer

The drainage layer materials normally used will have a porosity of at least 30%. Filter layer materials may have a lower porosity, but the value is easily measured by simple tests (**Chapter 30**).

A flow control structure may be required to constrain the rate of water discharged from the system. Due to the small runoff areas likely to be discharging to the system, it may be appropriate to link adjacent systems together so that the control system can be larger, to reduce the risk of blockage.

18.4.4 Volume control design

Contribution of bioretention systems to volume control should be evaluated using standard methods, based on expected infiltration rates and/or available attenuation storage and specified flow controls. Assessment of volumetric control should follow the method described in **Chapter 3**.

18.4.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the bioretention system. This can be achieved by installing an overflow pipe, weir or overflow structure above the design water storage level of the reservoir layer to convey excess flows downstream.

The exceedance flow capacity of the overflow should be confirmed using normal hydraulic assessment methods and analysis (weir, orifice and pipe flow). Exceedance flows beyond the capacity of the overflow should also be confirmed.

Any exceedance flow structure should be located in the biofiltration basin and as close to the inlet as possible to minimise the flow path length for above-capacity flows, thus reducing the risk of scouring (**Section 18.8.2**).

18.5 TREATMENT DESIGN

Bioretention systems can provide very effective treatment functionality through:

- the removal of sediments (especially fine sediment) and associated pollutants (such as nutrients, free oils/grease and metals) by filtration through surface vegetation and groundcover

- the removal of fine particulates and associated contaminants by infiltration through the underlying filter medium layers – this provides treatment by filtration, extended detention treatment and some biological uptake by vegetation and subsoil biota
- the removal of dissolved pollutants by sorption of pollutants to the filter medium.

The sizing of the bioretention surface area to deliver effective treatment is presented in **Box 18.1** – due to its links with hydraulic performance of the system.

The acceptability of allowing infiltration from the bioretention component will depend on the extent of the likely runoff contamination and site characteristics (see **Chapter 4, Table 4.3**).

Correctly designed and maintained bioretention systems have been shown, in numerous studies, to retain pollutants, even when receiving snow melt that contains de-icing salt constituents (Muthanna *et al*, 2007). Pollutant removal efficiencies of bioretention systems that are designed in accordance with the guidelines from FAWB (2009) are summarised in **Table 18.1**. Note that all quoted removal efficiencies are event specific and will depend on factors such as antecedent conditions.

TABLE 18.1 Pollution removal for bioretention systems designed to FAWB guidelines (after FAWB, 2009)

Pollutant	Typical removal efficiency
TSS	> 90%
Total phosphorous	> 80%
Nitrogen	50% on average
Metals (zinc, lead, cadmium)	> 90%
Metals (copper)	up to 60%

Evidence of the pollutant removal efficiencies of bioretention components, from the International BMP database is presented in **Chapter 26, Annex 3**.

Vegetation that grows in the filter medium enhances its function by trapping and absorbing physical pollutants and preventing erosion of the filter medium. It also improves the performance of the system by continuously breaking up the soil through plant growth to prevent clogging of the system, and providing biofilms on plant roots that pollutants can absorb or otherwise adhere to. While the type of vegetation varies depending on landscape requirements and climate, the filtration process generally improves with denser and higher vegetation. The type of plants used in bioretention systems affects the treatment performance. A study by the FAWB (2008) and others has found that there is marked variation in pollutant removal per unit plant mass between different species. The key factors that should therefore be considered in design are:

- plants that are well-adapted to ephemeral wet/dry conditions and have extensive root systems are likely to be most effective for treatment
- shallow-rooted plants are not particularly effective at nitrogen removal
- incorporating submerged zones will help maintain vegetation and avoid nitrogen spikes following dry periods of weather.

Soil filter media should be specified to meet the FAWB (2009) guidelines, as this appears to be most effective for pollution removal (**Chapter 30**). For smaller-scale rain gardens that are only collecting roof water, the FAWB guidelines may be too onerous, although the permeability requirements should be retained if the water leaves via an underdrain. Proprietary filter media should have demonstrated performance characteristics that are verified by an independent test organisation.

18.6 AMENITY DESIGN

Bioretention systems are very flexible in terms of size and appearance. They can deliver significant aesthetic benefits by incorporating vegetation into streetscape and general landscape features. They can be easily integrated into a variety of urban space including car parks, pedestrian areas, streetscapes, plazas and forecourts. They can form part of the local landscape as unobtrusive features or they can be prominent features contributing strongly to urban space and/or building design, but they should always be sensitive to landscape requirements and aim to enhance community areas. As rain gardens they can take small areas of roof water and can be located in any green space or can be hard features such as raised planters on patios; as bioretention swales along the road edge they can assist in defining the boundary of the road or green street corridors.

Bioretention systems can be used to treat runoff before use for non-potable requirements, and they can deliver water-efficient landscaping, particularly in dry areas, by storing runoff as a saturated layer beneath the system, creating a reservoir that can be accessed by overlying plants. Bioretention systems are also potentially beneficial to the local microclimate by cooling air through evapotranspiration.

Fencing of bioretention systems is generally not desirable as it may reduce the amenity benefits provided by the facility and make maintenance more difficult.

18.7 BIODIVERSITY DESIGN

Bioretention systems can provide quality habitat conditions for wildlife, contributing positively to biodiversity enhancement in urban areas. The systems are relatively flexible in terms of the planting that can be included, although native species are desirable to satisfy biodiversity action plans. Therefore they can be designed to support local biodiversity requirements where appropriate, working with ecologists and horticultural/arboricultural experts.

18.8 PHYSICAL SPECIFICATIONS

18.8.1 Pre-treatment and inlets

Inlets need to be designed to allow water to run onto the surface of the filter medium without causing scour or damage to vegetation and so that inflows are uniformly distributed over the filter surface area to maximise treatment potential. They should also have minimal risk of blockage. They need sufficient hydraulic capacity, and this should be confirmed by the usual analysis methods (**Chapter 28**). For simple rain gardens the inlet is often just a surface channel lined with granite sets or any other shallow channel construction that fits the landscape design. A forebay is not normally provided in simple small systems where sediment loads are low.

For bioretention systems draining roads or larger areas, the systems can be either on-line or off-line, and can have specific point inlets or over-the-edge flow into the system as shown in **Figure 18.10**. Kerb cuts are the best form of inlet from roads and other surfaces and should be at least 500 mm wide to minimise the risk of blockage with a large radius to the upstream kerb to promote flow into the system. They should include erosion protection downstream to dissipate energy. For larger systems or where sediment loads are high, a sediment forebay should be provided to trap sediment in an easily accessible area otherwise silt will tend to collect around the inlet, gradually extending into and blinding the surface of the filter. Forebays should be unobtrusive and appropriate to the size and design of the bioretention system. An area of dense vegetation at the inlet can also help with sediment management.

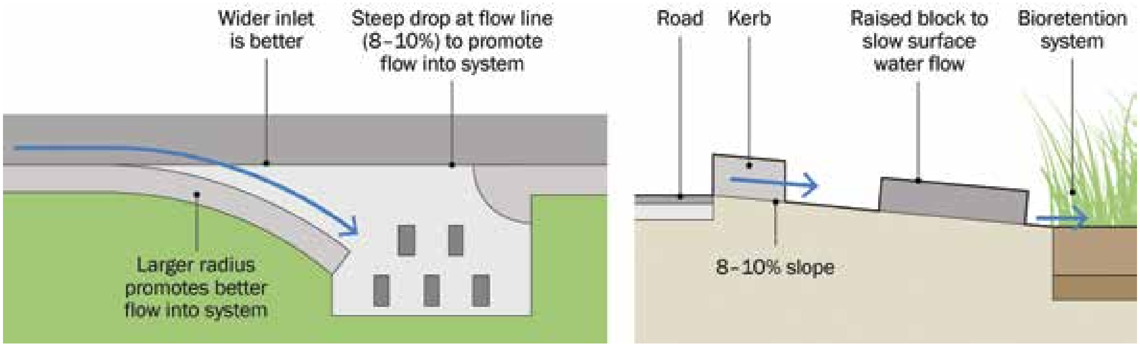

Figure 18.10 Inlets to a bioretention system as used in Lambeth, London (courtesy Lambeth Council)

Figure 18.11 Example of a bioretention system with a simple sediment forebay, Nottingham (courtesy Environment Agency)

Figure 18.12 Bioretention system inundated during heavy rain, showing submerged forebay (front left), Portland, Oregon (courtesy Environmental Services, City of Portland)

Pre-treatment is usually only required for high sediment or gross pollutants loadings (ie not roof runoff). This can be achieved using a filter strip, gravel strip or two-cell design that has a forebay from which sediment can be easily removed (**Equation 18.2**). An alternative to a forebay for larger systems is to provide an inlet pond (effectively a submerged forebay) (**Figure 18.12**).

Portland, Oregon (courtesy Illman Young)

Bath, Somerset (courtesy Grant Associates)

Figure 18.13 Example of inlets for bioretention systems

EQ. 18.2 **Forebay design**

If a forebay is provided, it can be sized following the guidance from Water by Design (2012). The forebay should remove 80% of particles that are greater than 1 mm diameter from the water quality design event (**Chapter 4**) and provide sufficient storage for the coarse sediment to build up between maintenance events. The forebay should also provide energy dissipation of the incoming flows. Forebays should be separate from the filter medium and should not be constructed over it.

The volume of the forebay is determined using the following equation:

$$V_s = A_c \; R \; L_o \; F_c$$

where:

V_s = volume of forebay sediment storage required (m^3)

A_c = contributing catchment area (ha)

R = capture efficiency (0.8 recommended)

L_0 = sediment loading rate (m^3/ha/year) (for example guidance see Wilson *et al*, 2004)

F_c = desired clean-out frequency (years)

The area of the forebay is determined using the following equation which is modified from Fair and Gayer (1954):

where:

$$R = 1 - \left[1 + \frac{v_s \, A_f}{n \, Q}\right]^{-n}$$

R = fraction of target sediment removed (0.8 recommended)

V_s = settling velocity of target sediment (0.1 m/s for 1 mm particle)

Q = 1:1 year, critical duration flow rate (m^3/s)

A_f = minimum forebay area for sediment capture (m^2)

n = turbulence or short-circuiting parameter (0.5 recommended)

The depth is determined by dividing the volume by the area and should not be greater than 300 mm. For smaller forebays less than 10 m^2, the depth should not exceed 200 mm. Note that to prevent resuspension of sediment and minimise the frequency of maintenance, the design may be based on a higher return period event, especially if the system is designed to also provide attenuation for these events.

18.8.2 Underdrains and outlets

Underdrains and outlets should be designed using conventional hydraulic design methods to ensure that the system can carry away the filtering water and to ensure that the overlying soils do not become saturated (the underdrains should have a hydraulic capacity exceeding that of the surrounding soils).

The following need to be checked:

a) perforations in the pipe are adequate to pass the maximum filtration rate (using orifice equations – **Section 28.5.2**)

b) the pipe has sufficient capacity to convey the design flows (this component should be oversized to ensure that it does not become a choke in the system)

c) material in the drainage layer will not wash into the perforated pipes – a useful guide is to check that the D85 (85th percentile particle size) of the drainage layer is greater than the pipe perforation diameter (FAWB, 2009).

The underdrains should be connected to a positive outflow and should be constructed using slotted pipes or geocellular units. Underdrains are not always required if the system is allowing water to infiltrate into the ground (this will depend on the infiltration capacity of the soils and the risks of system clogging), but where they are used they should be connected to an outfall.

If the design objective for the underdrain is to collect all the filtered water, the bottom of the system can be shaped to define a flow path towards the underdrain (**Figure 18.14**). However, if the goal is to facilitate infiltration, then the base should be flat (particularly where the underdrain pipe is raised above the base).

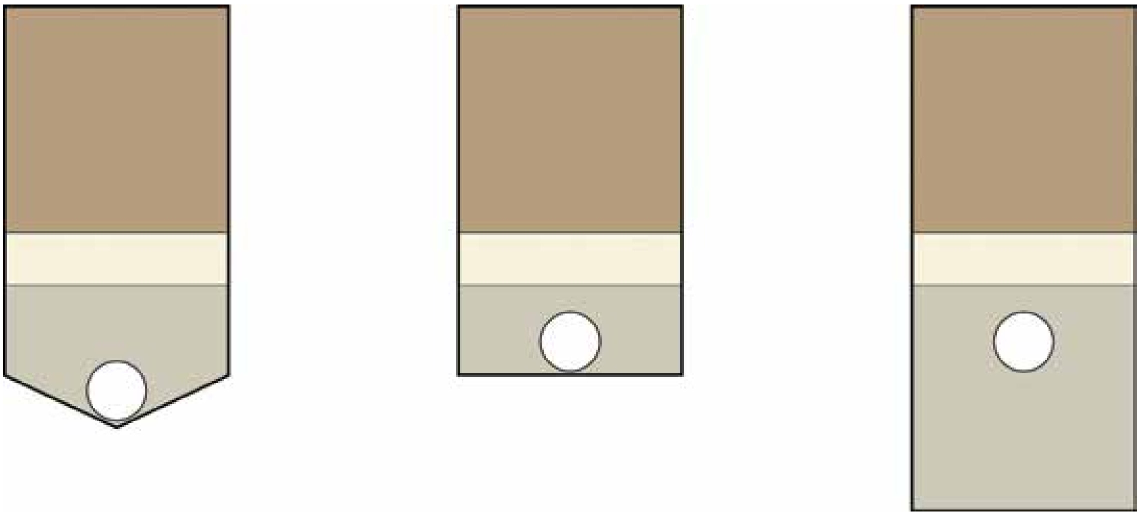

Figure 18.14 Shaping the bottom of a system

For simple rain gardens taking roof water, where there is no underdrain, a simple outfall is required. Variations of the simple protected orifice flow control, as shown in **Figure 18.15**, have been used successfully in the UK.

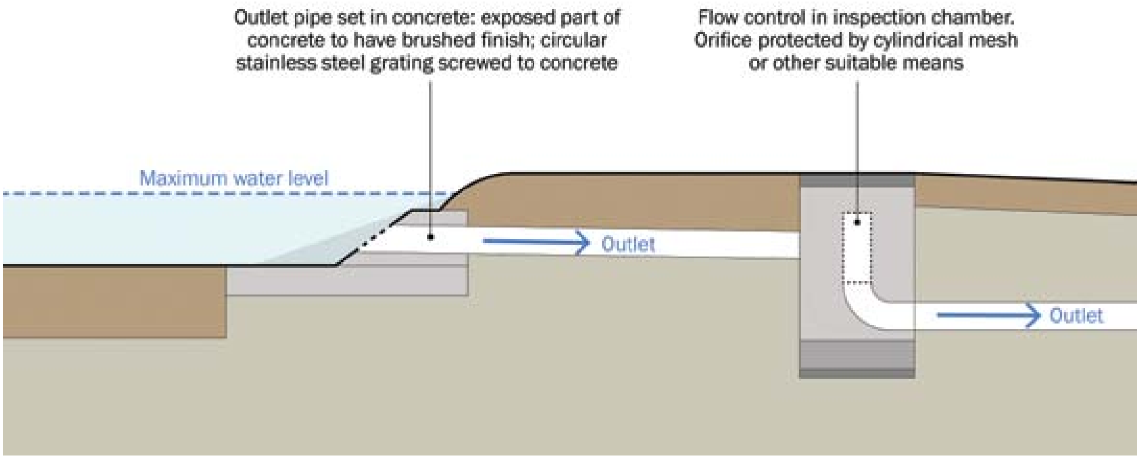

Figure 18.15 Outfall from simple rain garden (courtesy EPG and Illman Young)

For most systems, an overflow structure and non-erosive overflow channel should be provided to safely pass flows in excess of the bioretention storage capacity to the downstream drainage system. This should be sized to convey the overflow event, and can often be a small 150 mm diameter pipe. It should be set at the required height to operate when the overflow event occurs. The overflow outlet should generally be as close as possible to the inlet so that the flow path across the surface of the filter medium is minimised for larger flows (**Figures 18.16 and 18.17**). However, for smaller retrofit systems this is not always possible, especially if using existing drainage gullies as the overflow.

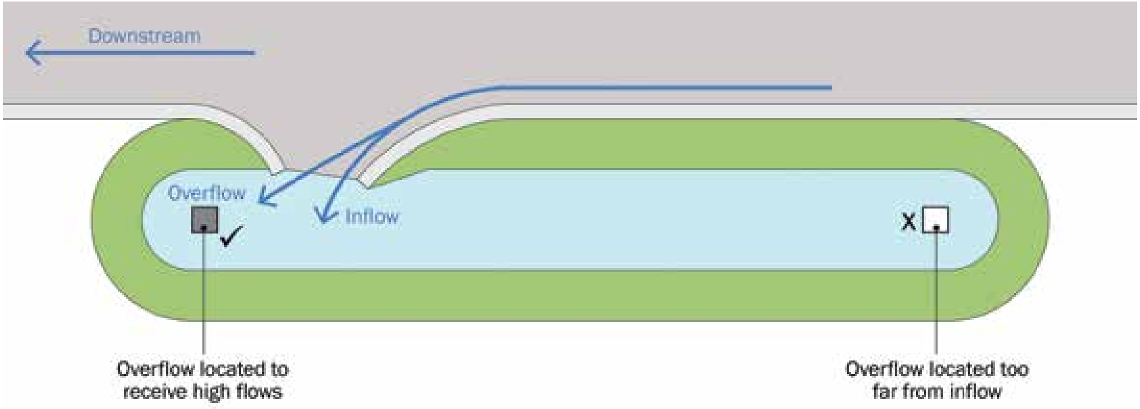

Figure 18.16 Inlet and overflow outlet configuration (small scale) (after Water by Design, 2012)

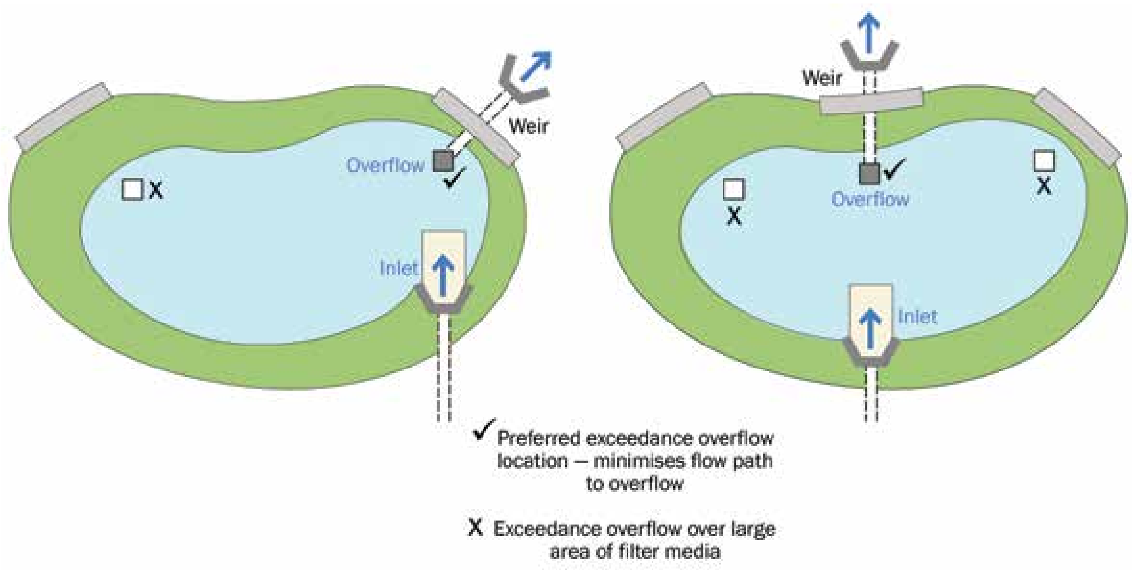

Figure 18.17 Inlet and overflow outlet configuration (medium/large scale) (after Water by Design, 2012)

Overflow systems/routes are also required where the flow capacity of a bioretention system is exceeded; these should generally be located at the downstream end, but they may need to be staggered along the system depending on the length of the component.

Inspection pipes should be provided to underdrains to provide access for cleaning and monitoring.

▶ Outlet structures are discussed in more detail in **Chapter 28**.

Figure 18.18 Example of a simple rain garden overflow, Portland (courtesy Illman Young)

18.9 MATERIALS

18.9.1 Mulch layer (if required)

The use of an organic mulch should generally be avoided for systems where there is an overflow pit, owing to the risk of clogging. In the case of infiltration systems (with no overflow), a mulch may be used, but there is still a risk of excessive movement of material during high flows. A mulch layer (with a maximum depth of 75 mm) can be spread over the bioretention area to retain some soil moisture. Organic matting that degrades within six months, bonded fibre matric mulches or a layer of gravel can be used as an alternative to standard organic mulches. A gravel mulch may be valuable where there is a need to protect the soil from erosion or decrease the drop to the water storage zone (for safety reasons), while still maintaining an acceptable ponding volume; however, high planting densities should be used, to compensate for the reduced spread of plants.

The best performance and prevention of erosion is likely to be achieved by using plants that give good ground cover rather than a mulch.

18.9.2 Filter media

The filter medium should be sufficiently permeable to allow water to pass through it, so that the surface of the retention area does not become waterlogged. It also needs to contain sufficient organic material and plant nutrients to support the proposed vegetation.

Filter media should be correctly specified. An indicative specification is provided in **Box 18.1**, but others are available, and any specification should take into account site-specific requirements and constraints. If alternative specifications are used, the specification parameters should be clearly stated, so that in the event that a supplier ceases trading the filter material can still be replaced on a like-for-like basis. Note that this is a different specification from tree soil, and if trees are being planted in the system a soil scientist or arboriculturist should be consulted on the most appropriate specification for the system.

Incorrect specification can cause reduced hydraulic conductivity through over-compaction or structural collapse, leading to reduction in treatment capacity and surface ponding, loss of vegetation etc. The filter medium should also be correctly installed with an appropriate level of compaction during installation to prevent migration of fine particles.

A filter medium that is placed uncompacted will initially show a very high hydraulic conductivity which will then rapidly decrease. So it is essential that testing of hydraulic conductivity be carried out on the compacted filter medium before installation.

BOX 18.1 Example specification for a bioretention filter medium

Saturated hydraulic conductivity (permeability)

The saturated hydraulic conductivity should be between 100 mm/h and 300 mm/h. This should be checked *in situ*, using the single ring infiltration test method as described in BS EN ISO 22282-5:2012.

(Note that where larger volumes of engineered soil are to be used, it is wise to test the hydraulic conductivity before delivery to site using a laboratory test. ASTM F1815-06 is commonly used in other applications such as sports pitches.)

Porosity

The total porosity should be > 30% when tested in accordance with BS 1377-2:1990).

Particle size distribution

Particle size distribution (PSD) is of secondary importance compared with saturated hydraulic conductivity. A material whose PSD falls within the following recommended range does not preclude the need for hydraulic conductivity testing, that is it does not guarantee that the

continued...

continued from...

BOX 18.1 Example specification for a bioretention filter medium

material will have a suitable hydraulic conductivity. However, the grading in **Table 18.2** provides a useful guide for selecting an appropriate material. The grading needs to be readily understood by both drainage and landscape/horticultural professionals, and each use a different standard format for presenting grading information. The grading in **Table 18.2** is presented in a standard engineering format.

Table 18.2 Example grading for a bioretention filter medium

Sieve size (mm)	% passing
6	100
2.0	90–100
0.6	40–70
0.2	5–20
0.063	< 5

The specification could also be presented as follows (which may be more relevant to landscape practitioners):

- clay and silt (< 0.063 mm) < 5%
- fine sand (0.063–0.2 mm) < 20%
- medium sand (0.2–0.6 mm) 35% to 65%
- coarse sand (0.60–2.0 mm) 50% to 60%
- fine gravel (2.0–6.0 mm) < 10%

The filter medium should be well-graded, and the composition should contain limited particle size range.

Organic matter content

Organic matter content should be 3–5% (w/w).

pH

pH should be 5.5–8.5 (1:2.5 soil/water extract)

Electrical conductivity (salinity)

Electrical conductivity (EC) should be < 3300 µS/cm (1:2.5 soil/$CaSO_4$ extract)

Major plant nutrients

Total nitrogen should be 0.10–0.30%

Extractable phosphorus should be 16–100 mg/l

Extractable potassium should be 120–900 mg/l

(Methods of analysis in accordance with BS 3882:2015, unless otherwise stated.)

Horticultural assessment

Potential bioretention soils and test results should generally be assessed by a horticulturalist to ensure that they are capable of supporting a healthy vegetation community. This assessment should take into consideration delivery of nutrients to the system by surface water runoff. Any component or soil found to contain high levels of salt (as determined by EC measurements), high levels of clay or silt particles (exceeding the particle size limits set above), or any other extremes which may be considered retardant to plant growth should be rejected.

For simple rain gardens draining a small area of roof (< 20 m^2) the filter medium could be substituted by a 200–500 mm layer of engineered soil (**Section 30.4.2**) below the base, or, if the native soil is good quality subsoil, then an "amended soil" could be used comprising: 55% sand, 30% existing soil, 15% compost.

The material should be well mixed and should meet the permeability requirements specified in the bioretention and engineered soil specifications.

18.9.3 Transition layer or geotextile separator layer

The transition layer should be specified based on the geotechnical filter criteria described in **Chapter 30**, taking account of the grading of the filter medium and the drainage layer. The filter criteria ensure that soil particles cannot be washed from one layer to another. Alternatively a geotextile separator may be used, which should meet the geotextile filter criteria (**Chapter 30**).

18.9.4 Drainage layer

The drainage layer should be much more permeable than the filter medium. There are various materials that can meet this requirement and may be suitable as the drainage layer:

- filter drain materials – see **Section 30.4.1**
- sub-base materials used below pervious surfaces, such as 4/20 aggregate – see **Chapter 20**
- geocellular units – see **Chapter 21**

Materials such as crushed recycled concrete may be appropriate for the drainage layer, but they should not contain any fine particles that could wash out of the drainage layer, contaminating runoff and potentially blocking underdrain pipework. Crushed concrete should also be tested to make sure that it will not leach contaminants into the water.

18.10 LANDSCAPE DESIGN AND PLANTING

Plant selection will be dependent on design aspirations for the site. Planting in a bioretention system provides volumetric reduction of runoff, pollutant uptake through the soil and physical and chemical processes in the soil. Plants also affect the long-term hydraulic conductivity of the filter medium and help prevent erosion. The type of plants used in a bioretention system affects the system performance. The main criteria for plant selection are:

- surrounding landscape characteristics
- whether native or introduced species are appropriate
- availability of plants from local nurseries
- drought tolerance – capable of surviving extended dry periods
- tolerance of free-draining sandy soil
- tolerance of occasional inundation
- tolerance of expected pollution loads
- fibrous root structure propensity
- spreading growth form rather than clumping propensity.

Consideration should also be given to shade tolerance and height restrictions (eg for sight lines next to highways). The level of maintenance that plants will require is also an important consideration. Guidance on suitable plants for the UK is provided by the Bray *et al* (2012) but the choice is site specific and requires input from a landscape architect or other horticultural professional. Plant lists can lead to uniform standard design solutions and discourage creative site specific design, so plant lists are not provided in this manual.

In general, the same considerations apply for bioretention areas as for swales, and the choice of planting should recognise that different areas in the facility will be subject to different saturation levels. The side slopes will generally be dry for most of the time, whereas the base is well drained but will be subject to varying moisture content and saturation.

Two specific types of planting areas can be differentiated as follows:

a) **Ornamental planting areas** – these can also act as a bioretention areas where aesthetics are of key importance. If ornamental planting is applied, the retention area should be considered as a mass bed planting, so that foliage will cover the entire area at the end of the second growing season. A variety of species should be used to give interest all year round, with perennials giving colour from spring to autumn and ornamental grasses and evergreen or berry-producing shrubs ensuring that the area remains visually acceptable during the winter. Low maintenance ornamental species are most appropriate.

b) **Open space meadows** – these areas can be used for bioretention, and tend to have significantly reduced maintenance requirements. The planting used in this case tends to be a variety of native grasses interlaced with selections of wildflowers.

Derbyshire Street, London (courtesy Greysmith Associates)

Ribblesdale Road, Nottingham (courtesy Leicester City Council)

Portland, Oregon (courtesy Heriot-Watt University)

Portland, Oregon (courtesy Illman Young)

Portland, Oregon (courtesy Illman Young)

Figure 18.19 Example planting schemes for bioretention systems

Whatever planting is specified, the following aspects are important in successful establishment of the bioretention system or rain garden.

- Dense planting is necessary (typically in the order of 6–10 plants/m² (although this will be species specific). This increases root densities, which helps to maintain surface permeability.
- In larger systems, consider zoning, with areas away from inlets having different species that need to be more hardy.
- Shrubs are very effective plants in bioretention systems because of their moderately fibrous root system and large root biomass. They can provide dense vegetative barriers to deter public access if needed, and reduce weeds. A minimum of three types of shrubs should be used to give diversity, which protects against pests and disease. Herbaceous ground cover should be provided if the site conditions are suitable (at least three or four species) because it has fibrous roots, is fast growing and is effective at removing pollutants. Turf is not recommended because of limited tolerance to dry periods.
- Provide a range of growth forms where possible.

A typical planting layout is shown in **Figure 18.20**.

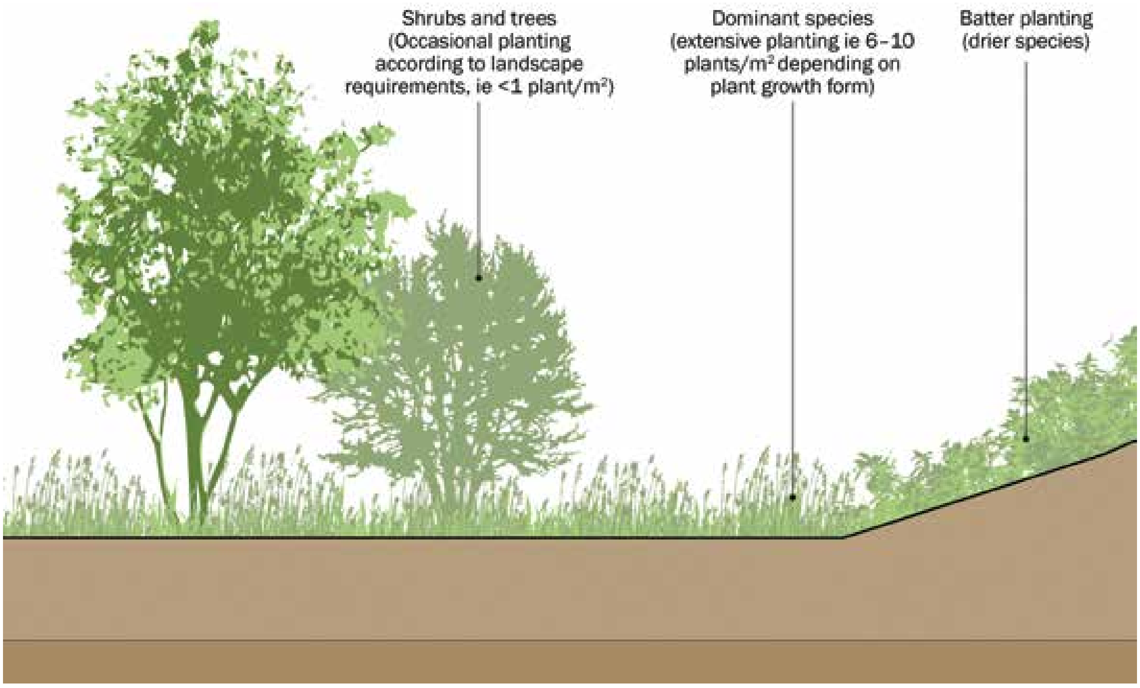

Figure 18.20 Typical planting layout

The batters or side slopes around bioretention systems should have at least 200 mm of topsoil on them. The topsoil should meet the requirements of BS 3882:2015.

Where trees are included in bioretention systems, they should not be provided with irrigation pipes that extend into the filter medium. This is because the pipes will allow water to short-circuit the filter and will reduce the effectiveness of the system. If trees stakes are used to support the trees they should be removed when no longer required and the holes filled in with filter medium (again to avoid short-circuiting).

▶ Further information on landscape and planting best practice is presented in **Chapter 29**.

18.11 CONSTRUCTION REQUIREMENTS

Bioretention areas should ideally be constructed at the end of development, to minimise erosion and sediment generation, and a dense and vigorous vegetative cover should be established over the contributing pervious catchment area before runoff is accepted into the facility. If this is impractical, bioretention areas should be protected from runoff by using silt fences or straw bales as recommended in Woods Ballard *et al* (2007).

In Australia there has been a significant issue with bioretention blinding, compaction and failure during the site construction phase. One approach to address this is to place the filter medium in the system and cover it with a temporary impermeable cover to collect all the silt and sediment that is washed into the depression during construction (ie the system is acting as a silt basin during construction). This impermeable layer and accumulated silt is removed once construction is completed and the system is planted. Relying on sediment fences and straw bales has not been found to be as effective as protecting the systems with a temporary cover.

To minimise the risk of premature system failure, the following points should be closely monitored during the construction of bioretention areas:

- Care should be taken not to over-compact the soils below the bioretention area, and particularly the filter and soil planting bed, as this will reduce infiltration capacities.
- To excavate a bioretention area, a backhoe excavator should be used, and construction plant should avoid running over the bioretention area. For smaller systems and rain gardens, hand excavation may be more suitable if access is limited.
- If mulch is required, it should be applied before planting. It should not be piled up around plants, as this will cause disease and encourage pests. It should be 50–75 mm thick and should be kept clear of plant stems by 50 mm to prevent excessive moisture around the stems.
- Care should be taken to ensure that geotextiles are not clogged or torn during construction.
- The filter medium should not be placed if it is saturated or if the ground below the system is saturated.

The filter medium should be tested to ensure that it meets the required criteria before placing (**Box 18.1**). It is important to establish the planting in the systems as quickly as possible. Watering, weeding and replanting will be required during the establishment period to ensure that greater than 90% of plants survive and give good cover.

The surface of the filter medium should be free of localised depressions so that water is distributed evenly across the surface and prevents localised ponding and clogging. The surface levels should be within a tolerance of ± 25 mm for smaller systems and ± 40 mm for systems with an area greater than 300 m^2. The thicknesses for the various layers should be constructed with a tolerance of + 25 mm (ie they should not be less than the design thickness). Levels around the edge of the system should be within ± 25 mm of design levels.

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety guidance is presented in **Chapter 36**.

18.12 OPERATION AND MAINTENANCE REQUIREMENTS

Dalrymple (2013) concluded that bioretention systems will typically require approximately 2.5 times more maintenance than typical landscape designs. Bioretention systems will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of bioretention systems is dependent on maintenance, and robust management plans will be required to ensure that maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance. Ease of access for maintenance and inspection is essential.

The main cause of failure of bioretention systems is clogging of the surface, which is easily visible. Underdrains and drainage layers are beneath the ground, and malfunctioning is not so easy to detect and therefore could potentially be ignored. However, the results of any malfunction are likely to cause surface ponding. The clogging of the surface or drainage layers can cause poor outflow water quality due to water bypassing the filter medium to the overflow more frequently than allowed for. During the first few months after installation, the system should be visually inspected after rainfall events, and the amount of deposition measured, to give the operator an idea of the expected rate of sediment deposition. After this initial period, systems should be inspected each quarter, to verify the appropriate level of maintenance.

▶ Further detail on waste management is provided in **Chapter 33**.

Adequate access should be provided for all bioretention areas for inspection and maintenance, including for the appropriate equipment and vehicles.

Litter picking should be frequent, as rubbish is detrimental to the visual appearance of bioretention systems. Frequent street sweeping in the catchment area will increase the time interval between cleaning out forebays or the filter surface and will reduce the loading of fine suspended solids that can potentially clog the filter medium.

All vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Maintenance responsibility for all systems should be placed with an appropriate organisation, and Maintenance Plans and schedules should be developed during the design phase. **Table 18.3** provides guidance on the type of operation and maintenance schedule that may be appropriate. The list of actions is not exhaustive and some actions may not always be required. The most intensive maintenance is required during the establishment period. Herbicides and pesticides (such as Roundup) and fertilizers should not be used on bioretention systems. This is because these pollutants will wash through the system quite easily.

Sediments excavated from pre-treatment devices that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation, to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on site, if there is an appropriate safe and acceptable location to do so. Proper disposal of sediment and debris removed must be ensured, and the environmental regulator should be approached for advice where there are any doubts concerning disposal options.

▶ Further detail on waste management is given in **Chapter 33**.

Specific maintenance needs of the bioretention area should be monitored, and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

In general, the maintenance for bioretention areas can often be undertaken as part of routine landscape maintenance.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

TABLE 18.3 Operation and maintenance requirements for bioretention systems

Maintenance schedule	Required action	Typical frequency
Regular inspections	Inspect infiltration surfaces for silting and ponding, record de-watering time of the facility and assess standing water levels in underdrain (if appropriate) to determine if maintenance is necessary	Quarterly
	Check operation of underdrains by inspection of flows after rain	Annually
	Assess plants for disease infection, poor growth, invasive species etc and replace as necessary	Quarterly
	Inspect inlets and outlets for blockage	Quarterly
Regular maintenance	Remove litter and surface debris and weeds	Quarterly (or more frequently for tidiness or aesthetic reasons)
	Replace any plants, to maintain planting density	As required
	Remove sediment, litter and debris build-up from around inlets or from forebays	Quarterly to biannually
Occasional maintenance	Infill any holes or scour in the filter medium, improve erosion protection if required	As required
	Repair minor accumulations of silt by raking away surface mulch, scarifying surface of medium and replacing mulch	As required
Remedial actions	Remove and replace filter medium and vegetation above	As required but likely to be > 20 years

▶ Generic health and safety guidance is presented in **Chapter 36**.

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Statutes

ASTM F1815-06 *Standard test methods for saturated hydraulic conductivity, water retention, porosity, and bulk density of athletic field rootzones*

BS 1377-2:1990 *Methods of test for soils for civil engineering purposes. Classification tests*

BS EN ISO 22282-5:2012 *Geotechnical investigation and testing. Geohydraulic testing. Infiltrometer tests*

BS 3882:2015 *Specification for topsoil*

Construction (Design and Management) Regulations (CDM) 2015

Image courtesy Illman Young

19 TREES

Contents

Chapter 19 Trees

This chapter provides guidance on the design of SuDS schemes that use trees. This chapter does not provide guidance on the wider issues of using trees in urban planning and design.

▶ *Appendix C, Section C.5.2 demonstrates how to design an infiltration treee pit for a civic street.*

19.1 GENERAL DESCRIPTION

Trees can help protect and enhance the urban environment in a number of important ways (**Figure 19.1**). This includes:

- contributing to effective surface water management strategies
- adding beauty and character to the urban landscape, which in turn helps to improve the health and wellbeing of local communities, and raise the value of residential and commercial areas
- reducing annual building energy consumption by moderating the local climate – that is, keeping it cooler in summer and warmer in winter
- filtering harmful pollutants from the air
- masking and reducing unwanted noise
- creating vital wildlife habitats, enabling more species to thrive in the urban environment
- helping to slow down cars (trees can be used as an alternative to bollards and speed bumps or to reinforce the presence and enhance the role of a central reservation)
- providing a source of food
- absorbing and storing atmospheric carbon dioxide (carbon sequestration).

Trees and their planting structures provide benefits to surface water management in the following ways:

- **Transpiration** – This is the process by which water, taken in from the soil by tree roots, is evaporated through the pores or stomata on the surface of leaves (Nisbet, 2005). Trees draw large quantities of water from the soil, which can contribute to reducing runoff volumes (**Box 19.1**).
- **Interception** – Leaves, branches and trunk surfaces intercept (store and allow the water to evaporate) and absorb rainfall, reducing the amount of water that reaches the ground, delaying the onset and reducing the volume of runoff (**Box 19.1**).
- **Increased infiltration** – Root growth and decomposition increase soil infiltration capacity and rate, reducing runoff volumes.
- **Phytoremediation** – In the process of drawing water from the soil, trees also take up trace amounts of harmful chemicals, including metals, organic compounds, fuels and solvents that are present in the soil. Inside the tree, these chemicals can be transformed into less harmful substances, used as nutrients and/or stored in roots, stems and leaves.

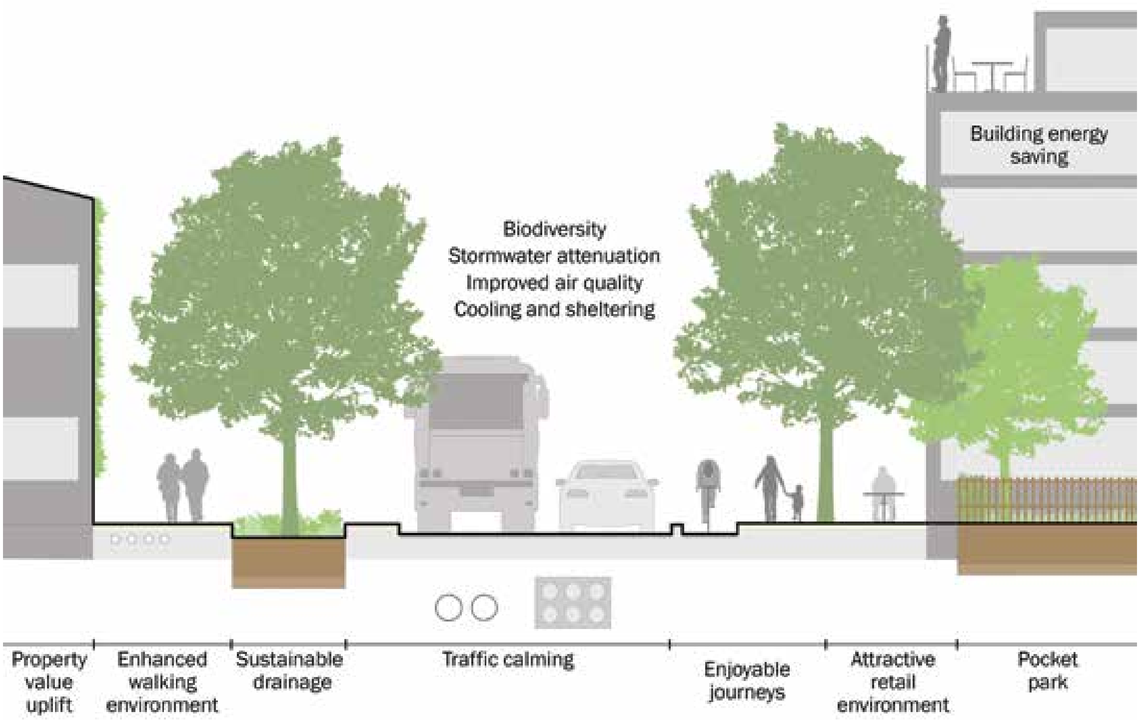

Figure 19.1 How trees can enhance an urban street (after TDAG, 2014)

Figure 19.2 Percival Triangle, Islington (courtesy Crasemann Landscape Architecture)

BOX 19.1 **Trees and runoff volume reduction**

A study in the USA (Geiger, 2002) found that tree canopy Interception storage is usually filled after about 10 minutes. The amount of canopy Interception provided by trees is influenced by rainfall intensity, storm duration, sunlight, temperature, humidity, wind speed and the species of tree.

Nisbet (2005) reports that studies in the UK have found that 25–45% of annual rainfall is typically taken up by Interception from conifer stands, compared with 10–25% for broadleaves (Calder *et al*, 2003). Transpiration rates, on the other hand, vary little between the two forest types, with annual losses mainly falling within a relatively narrow range of 300–350 mm (Roberts, 1983). Research in southern England, however, has found higher annual transpiration losses for broadleaves of 360–390 mm (Harding *et al*, 1992). Therefore, if both Interception and transpiration are considered together, and assuming an annual rainfall of 1000 mm, conifers could be expected to use some 550–800 mm of water compared with 400–640 mm for broadleaves. Preliminary research results from the University of Manchester indicate that trees can reduce runoff by as much as 80% compared to asphalt (Armson *et al*, 2011).

Trees can be planted within a range of infiltration SuDS components (eg bioretention systems, detention basins, swales) to improve their performance, or they can be used as standalone features within soil-filled tree pits, tree planters or structural soils (**Figure 19.3**).

Tree pits and planters can be designed to collect and attenuate runoff by providing additional storage within the underlying structure. The soils around trees can also be used to filter out pollutants from runoff directly. This chapter is concerned specifically with the use of trees in planting beds, pits, structural soils below pavements and similar structures as part of the surface water management system.

Comprehensive information on the design of trees in hard landscapes, including as part of SuDS, is provided by TDAG (2014).

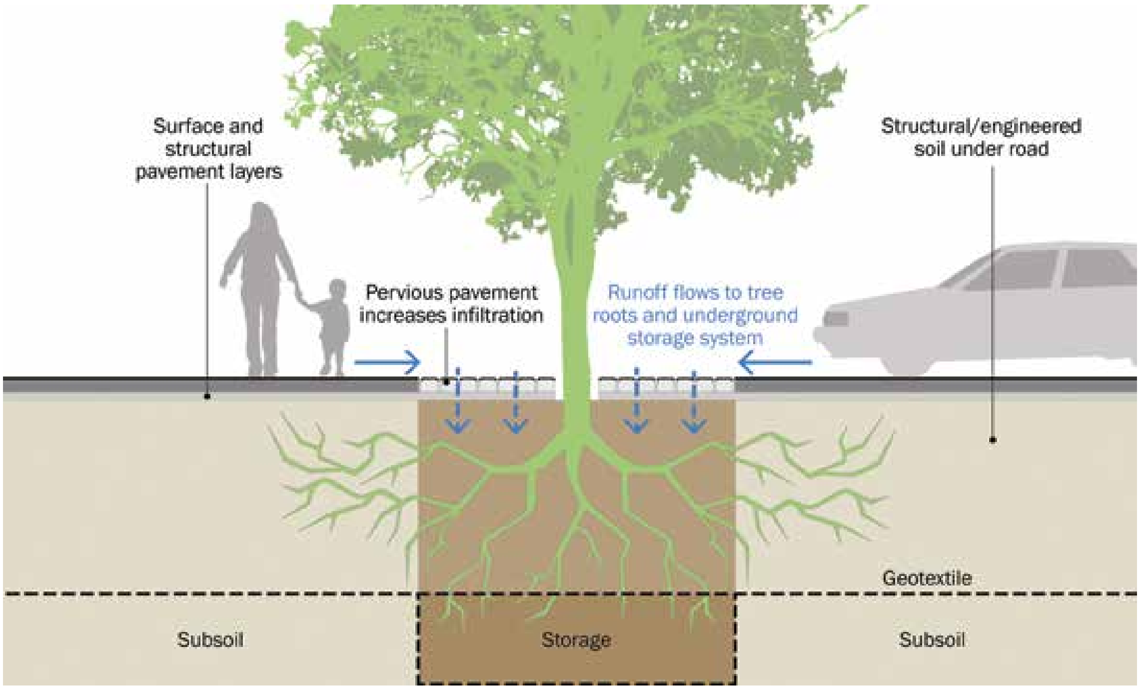

Figure 19.3 Collection of surface water runoff for trees

Oxfordshire (courtesy Leicester City Council)

Upton

Figure 19.4 Trees used to enhance swales

19.2 GENERAL DESIGN CONSIDERATIONS

Trees are only intended to manage surface water runoff from the local area (typically a similar area that would drain to a single road gulley). They should not be used to manage large volumes of water that have been collected via numerous gullies and/or channels within a large sub-catchment.

Trees require sufficient space, appropriate soil, sufficient gas exchange, adequate drainage and a supply of water. Soil properties and soil volume are vital for growing trees in urban landscapes and using them successfully as a means of managing runoff. More detailed guidance is provided by TDAG (2014) and in BS 8545:2014. The key is to consider rooting volume early in the design process so that it can be provided cost effectively.

Any tree pit or planter should provide adequate rootable soil volume and appropriate levels of water and air availability to the roots so as not to inhibit tree growth. These factors are influenced by a soil's porosity (amount of available pore space), permeability (how interconnected pore spaces are) and infiltration rate (how quickly the water moves through the soil). Roots also require sufficient organic material and nutrients within the soil, and require suitable drainage so that they do not become waterlogged. There is a balancing act between providing enough water for the trees' needs and preventing the soils becoming saturated. This is achieved by ensuring that water storage is below the rootable soil volume for the majority of the time (occasional inundation of roots may be acceptable – seek the advice of an arboriculturalist) and allowing water to flow freely below the whole area of rootable soil.

The availability of a sufficient water supply to the tree is crucial. Blunt (2008) suggested that in a dry year trees greater than 15 m height required 60–150 m^3 of water from the soil during the growing season. The largest tree took 240 m^3 and a small 10 m high birch took 30 m^3. It is, therefore, important to ensure that the runoff area draining to the tree will provide sufficient water for when it is fully grown. This needs to take into account the likely rainfall during the growing season, the storage capacity within the soil rooting volume, the rate of evaporation from the soil and the risk of dry years.

Designing the tree planting zone to accommodate the largest size tree possible will increase its capacity to manage runoff. Mature, large species trees with their large, dense canopies manage the most surface water runoff, and should be considered where the location is appropriate. Big trees require large volumes of suitable soil and above-ground space to grow. If too little soil is available, the tree will not reach full stature, regardless of what species of tree is planted. Poorly designed sites – those lacking adequate soil and space – generally require continuous, costly plant healthcare and often continual replacement of trees.

▶ Guidance on appropriate soil volumes is provided in **Section 19.8.2**.

It is important to consider the likely tree rooting characteristics of proposed trees to ensure tree viability and stability in the urban environment. Detailed guidance is provide in Crow (2005), which notes in particular that tree roots do not occur in significant quantities at substantial depths (eg > 2 m) in the soil profile (typically 90–99% of a tree's total root length occurs in the upper 1 m of soil). Guidance on designing building foundations near trees is provided in Chapter 4.2 of NHBC (2014).

Trees for SuDS will tend to be located in an urban environment, and street trees in particular can be subject to conditions that make it difficult for them to thrive. The main risks are soil compaction by vehicles and limited access to air and water for the roots.

There are various engineering structures that can be used to improve growing conditions for urban trees by expanding the rooting environment as much as possible beneath paved surfaces using load-bearing systems to avoid soil compaction around the roots (TDAG, 2014). These are discussed in the subsections below.

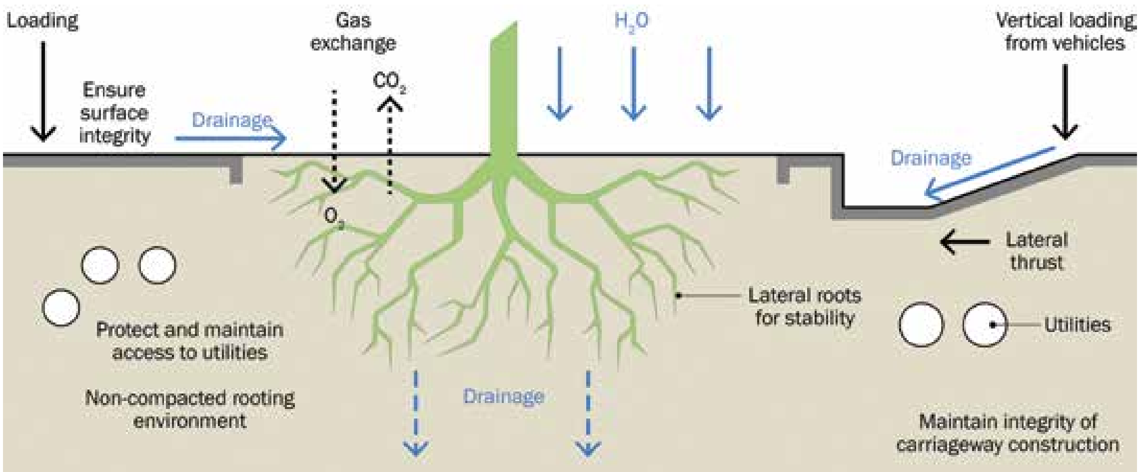

Figure 19.5 Properties of a tree system draining surface water from a road highway (after TDAG, 2014)

The acceptability of infiltration from a tree pit should be determined by following the guidance provided in **Section 25.2**, complying with all relevant requirements for infiltration systems with respect to ground stability, depth to water table etc and **Section 26.7** with respect to the protection of groundwater. The maximum likely groundwater level should always be at least 1 m below the lowest level of the tree pit, where infiltration can occur.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

Figure 19.6 Tree pit in Bourke Street, Melbourne

19.2.1 Structural growing media

Structural growing media refers to a group of soil-and-gravel mixes that are designed to support tree growth and serve as a sub-base for pavements. Structural growing media are highly porous, engineered aggregate mixes designed to be used under asphalt and concrete pavements as the load-bearing and levelling layer.

The three main types of structural growing media are as follows:

Sand-based substrates (also known as tree soils) – These comprise predominantly medium to coarse sand (0.2–2 mm) which is usually blended with a fine-grade green compost (providing an organic matter content of 2–4%) and 2–4% clay to add suitable water and nutrient retention properties. An example of this type of growing medium is the Amsterdam Tree Soil. More recently, variations have been developed that include a higher proportion of coarser sands to provide more air voids after compaction (eg Rotterdam Tree Soil). Mixes using recycled glass are also available. Their use is limited to untrafficked paved areas such as pedestrian areas with no vehicles and cycle tracks, where high levels of compaction are not required.

Medium-sized aggregate substrates – This uses a mix of angular aggregate that can be compacted to 95% of maximum dry density while still retaining void space between the angular particles. The void space is filled with soil. The coarse aggregate particles form a matrix that supports and distributes the loads from vehicles. This prevents compaction of the finer tree soil in which tree roots can grow, and prevents heaving of the pavement around the tree. There are many variations of the aggregate/soil mix but typically the aggregate will be 25–100 mm diameter and the proportion of soil is around 20–35%. Because the load-bearing capacity of the aggregate depends on the strength and durability of the particles, it is recommended that, where it is used below trafficked areas, it meets the durability and particle shape requirements for sub-base used below pervious surfaces (**Chapter 20**). The soil element can be various mixes of clay, sand and compost. This type of substrate can be used below lightly trafficked areas such as car parks.

Stone skeleton substrates – Also known as the Stockholm system (**Figure 19.7**), this is similar to the medium-sized aggregate substrates but uses larger aggregate particles in a base layer of 100–150 mm. The base layer is covered by a layer of 63–90 mm aggregate. The aggregates are compacted and soil flushed into the spaces between the larger particles. The system is provided with inlets that allow surface water and air to freely enter the substrate. The system can support heavier traffic loads than the above systems, for example HGVs and buses.

Figure 19.7 The use of structural growing media in retrofitting (a) and new-build (b) (courtesy Björn Embrén)

It should be noted that the medium-sized aggregate and the stone skeleton substrates typically only have 10–25% void space to support root growth and accommodate surface water runoff. Designers should therefore take care to ensure that each tree has sufficient volume of growing medium for its lifespan.

Trees are sensitive to pH (acidity or alkalinity) and pH can significantly affect the life and health of a tree and its ability to absorb nutrients. When using structural growing media, the pH of the soil and water will be influenced by the type of aggregate used in the mix, and tree species should be used that are compatible with the pH of the growing environment and the structural growing medium (**Section 19.9.2**).

19.2.2 Modular structures

Modular structures, referred to as "crate systems" by TDAG (2014), are cuboid plastic, concrete, plastic/steel or plastic/concrete structures that provide a load-bearing structure into which the substrate is placed (**Figure 19.8**). The structure supports the loads from the overlying pavement and prevents compaction of the substrate. They can be used to support car parks and roads and to prevent compaction of the tree soil in a similar manner to the course aggregate in a structural growing medium. The structures can provide a guaranteed volume of soil for the tree roots, an extra volume for surface water runoff attenuation and structural support to prevent the soil becoming compacted at the surface. They are usually covered with grilles, and extend below the adjacent hard surfacing.

The load-bearing capacity of the structures and the design requirements will depend on the material from which they are made. Many of the considerations for geocellular structures will also apply to plastic systems (**Chapter 21**). The structural element comprises a small proportion of the overall volume compared to the aggregate based systems, so there is a greater rootable volume available.

Figure 19.8 Placement of modular structures in a tree pit (courtesy Consulting with Trees)

Figure 19.9 Pinning out of cellular confinement system and aggregate infill (courtesy Infra Green Solutions Limited)

19.2.3 Raft systems

Raft systems provide a planar structural layer that is constructed over the rooting environment. The raft distributes the concentrated wheel and other loads across a wider area, to prevent damage to the soil structure and help absorb loads resulting from any required compaction of overlying layers. Also, the raft allows free movement of oxygen and water to root systems.

There are two types of raft system, as follows.

1. **Cellular confinement systems** – These are also referred to as geocells, which should not be confused with large-scale geocells constructed using geogrids below embankments or anti-compaction mats. These are a series of HDPE strips that are opened up and pinned to provide a series of honeycomb-shaped cells that are filled with coarse aggregate (typically 4–40 mm or 20–40 mm) to promote free air and water exchange with the soils below (**Figure 19.9**). These have been widely used in the construction of unsurfaced roads and for roads and rail tracks across weak ground since the late 1970s, and they are normally designed following guidance provided by the US Army Corp of Engineers (USACE). Other more rigorous analysis methods are being developed, but they have not gained wide acceptance at the present time.
2. **Geocellular sub-base replacement systems** – These are geocellular units that have joints that provide a structural connection so that the system acts as a raft to distribute load (**Figure 19.10**).

The units can be filled with soil to provide a rooting environment, and they have been used on several schemes in the Netherlands for this purpose.

▶ Further advice on geocellular systems is provided in **Chapter 21**.

Either of these systems can be designed to support traffic loads from any road-going vehicles in the UK including below highways (subject to approval from the highway authority).

The main concern with either of these systems is access to buried utilities, and accidental excavation. They should be used in appropriate situations with due regard to the presence of services.

Figure 19.10 Geocellular systems for trees, showing filling of geocellular rafts with structural growing medium (courtesy Permavoid Limited and EPG Limited)

19.2.4 Tree planters

Tree planters are essentially bioretention systems (**Chapter 18**) with trees in them, to enhance their capacity and performance, and/or to deliver amenity and biodiversity benefits. They have similar functionality and design requirements to standard tree pits, but have an open surface and generally a larger surface area, so their overall appearance is different.

Western Harbour, Malmö, Sweden

Portland, Oregan, USA

Figure 19.11 Tree planters (courtesy Illman Young)

Where the sensitivity and/or vulnerability of groundwater lying beneath a tree means that infiltration from contaminated surface runoff should be prevented, tree pits/planters etc should be designed with an impermeable geomembrane liner and positive drainage system to prevent waterlogging.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

The inclusion or retention of trees in central reservations or on footways sometimes gives rise to safety concerns, and consideration should always be given to ensuring that sight lines are not put at risk by tree planting proposals. Any protective surface grilles or other protection overlying tree pits should be designed to minimise the risk of damage by potential transient loadings – which could cause trip hazards for pedestrians.

19.3 SELECTION AND SITING OF TREES

Suitable trees should be chosen on a site-by-site basis, based on the constraints and opportunities afforded by a particular location, and to achieve optimum delivery of hydraulic, water quality, amenity and biodiversity objectives. A landscape architect should advise on the most appropriate trees for a particular development scenario that are suitable for:

(a) the likely runoff characteristics (flow rates, volumes and likely contaminants)

(b) the nature of the soil into which it is to be planted

(c) the location and characteristics of the planting site (eg narrow canopy trees may be required for street locations).

▶ The principles of tree selection are presented in TDAG (2014).

The following characteristics tend to increase the effectiveness of trees in reducing surface water runoff and filtering pollutants (note that not all are complementary) (CRWA, 2009):

- widespreading and dense canopies
- long life expectancies
- fast growing rates
- high tolerance to summer drought
- tolerance of saturated soils
- resistance to air and water pollutants common in urban environments
- extensive root systems
- rough bark
- tomentose or dull foliage surface
- vertical branching structures.

Road salt is the most commonly used de-icing chemical in the UK. It is crushed rock salt, and the main component is sodium chloride. Both sodium and chloride ions can be harmful to some trees if there are excessive quantities in the soil. Salt damage occurs to trees through contamination of the soil around roots or by salt spray. Salt spray is much more likely on roads with fast-moving traffic, such as motorways and trunk roads. It is likely to be less of a problem where vehicles are moving at low speeds, such as car parks and minor roads. In medium/high permeability soils such as sands and gravels (where the residence time of the water in the soil around the tree roots is low), the risk of the salt negatively affecting the tree is low. Also, trees generally take up less water in winter, and so if exposed to only a few instances of chloride-contaminated water the effects are likely to be minimal. Furthermore, the amount of salt applied to roads across the UK has reduced over recent years owing to generally milder winters and more targeted gritting. An arboriculturist should be consulted to choose appropriate species that are tolerant of salt if it considered likely that salt in runoff will adversely affect tree health.

- Further advice is provided by Forest Research (2011).

It is important to locate tree pits at a reasonable distance from buried utility services such as electric cable and water pipes. Trenching works to repair the services can cut tree roots, and equally tree roots can damage utility infrastructure. There is no specific minimum distance (although utility providers may set required distances) and it will depend on the nature of the service, its resistance to movement and damage caused by trees and the consequence of any damage. However, the risk of damage can be minimised by installing root barriers around the rootable volume of soil (note that these can often be as simple as using standard large manhole rings, or geotextile fabrics specifically designed as root barriers). Underground utilities can be placed around and even through tree pits, geocellular crate systems and suspended pavement systems. However, all underground utilities should be protected from water and root penetration.

- Detailed guidance is provided in BS 5837:2012.

19.4 HYDRAULIC DESIGN

19.4.1 General

There may be opportunities for infiltration from tree pits, even in city centre environments, and it is usually worthwhile undertaking infiltration testing to confirm likely infiltration rates.

When structural soil or the tree pit or planter is being used to store surface water runoff before infiltration, the subsoil may become saturated at times, resulting in lower soil strength. A geotechnical engineer should be consulted to determine if a separation geotextile or geomembrane is necessary. Lateral flow through structural soils can also be extremely rapid, and if the sub-base is permeable or has some permeable areas, throughflow is likely to be fast, which should be taken into account in the design. If surrounding areas are impermeable, ponding is possible and in such situations overflow and underdrain outlets are likely to be required to prevent ponded water suffocating trees and to control flood risks effectively.

Individual trees are likely to be less effective than linked, integrated tree systems in controlling surface water runoff as the latter provide greater capacity, flexibility and opportunities to convey and utilise exceedance flows effectively. An integrated tree and green roof system is shown in **Figure 19.12**.

Figure 19.13 shows a linear tree pit where water can drain through resin bound gravel, below which a combination of modular crates at each tree pit site and gabions in between allow water to drain along the linear strip.

19.4.2 Interception design

Interception provided by the tree canopy will vary with tree type and will increase over the life of a tree as it grows. For the first few years the Interception may be negligible. It is therefore best to ignore this aspect in the hydraulic design of SuDS, while recognising that it will have a long-term benefit and will reduce volumetric runoff loads to the surface water system in the future.

Where water is directed towards a tree pit, and the tree pit is designed to facilitate even limited infiltration, then a check should be made to determine whether the tree is able to dispose of 5 mm rainfall depth over the contributing catchment area.

Where there is no infiltration, but the natural surface soils (or imported/re-engineered soils) have water storage capacity, then Interception design should follow the principles set out in **Section 24.8**.

19.4.3 Peak flow control design

Tree pits can help reduce flow rates from a site by facilitating infiltration and/or by providing attenuation storage. The available storage volume is provided by the void space in the soils in the pit:

Available attenuation storage in the tree pit

= Volume of tree pit × void ratio in the soil*/aggregate/geocellular layer designed to be the storage volume

Note

* Attenuation storage cannot be assessed to be delivered when using fine-grained tree soils

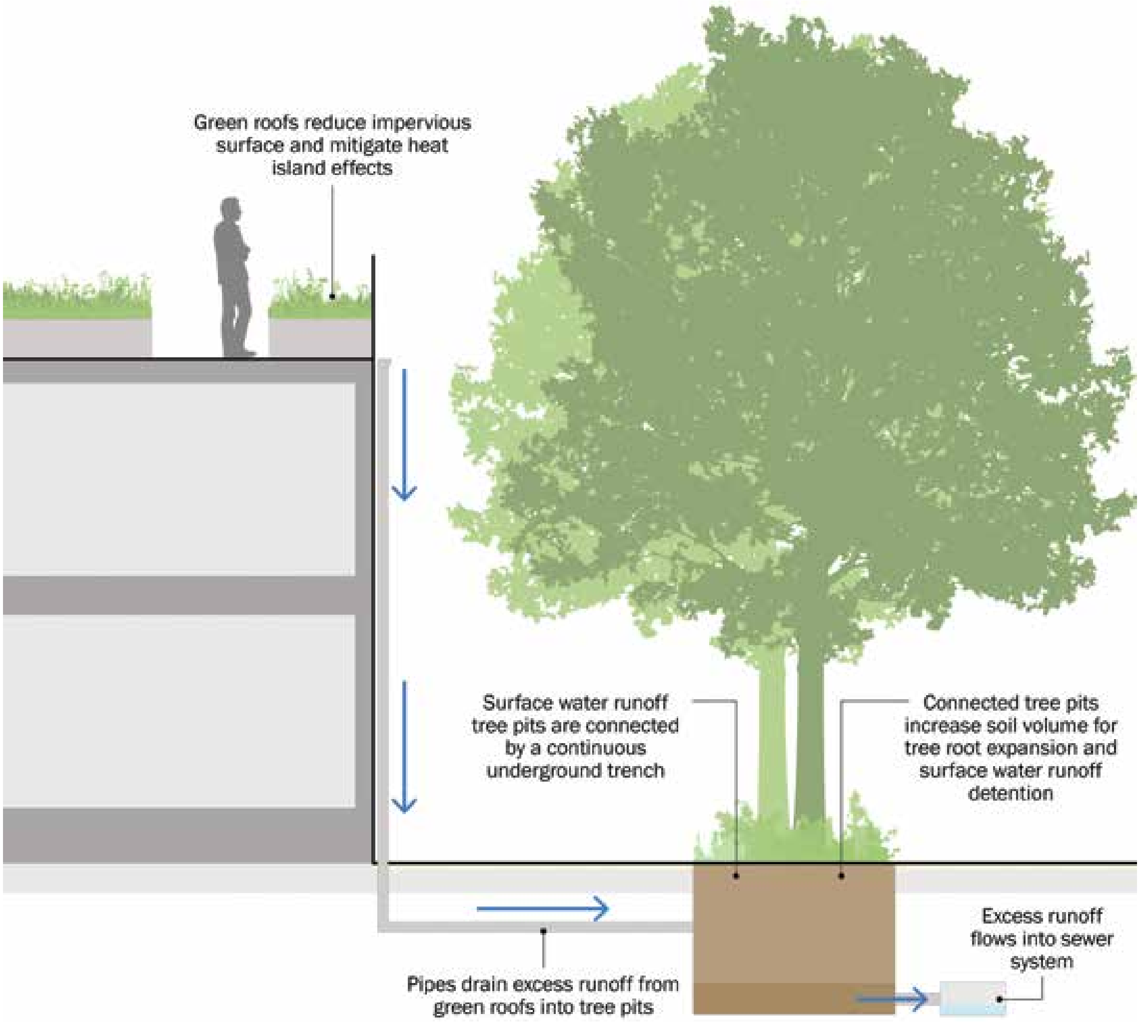

Figure 19.12 Integrated system of trees and green roofs

Figure 19.13 Linear tree pit, Leicester (courtesy Leicester City Council)

A flow control structure is generally required to constrain the rate of water discharged from the pit (**Chapter 28**). Owing to the small runoff areas likely to be discharging to the pit, it may be appropriate to link adjacent pits together so that the control system can be larger.

The level of stored water in the tree pit should be such that it will not adversely affect the health of the tree. Attenuation storage for peak flow control should normally be designed to drain down within 48 hours. This requirement should also ensure healthy root development (Day *et al*, 2008). If tree roots are likely to be inundated for longer than this on a regular basis, then flood tolerant species should be specified.

19.4.4 Volume control design

Contribution of tree pit systems to volume control should be evaluated using standard methods, based on expected infiltration rates and/or available attenuation storage and specified flow controls. Assessment of volumetric control should follow the method described in **Chapter 3**.

19.4.5 Exceedance flow design

An exceedance flow route will be required with rainfall events that exceed the design capacity of the tree pits or planters. This can be achieved by installing an overflow pipe above the design water storage level (**Figure 19.15**) or by overland flow routing.

The capacity of the overflow(s) should be confirmed using normal hydraulic assessment methods and analysis (weir, orifice and pipe flow) (**Chapter 24**). Exceedance flows beyond the capacity of the overflow(s) should also be reviewed (**Section 24.12**).

19.5 TREATMENT DESIGN

Tree pits will filter out pollutants from runoff and, by reducing the volume of runoff, will also help to reduce pollutant loadings to receiving surface waters. Good pollutant removal performance is required for all runoff events up to and including events which occur, on average, about once a year (termed here the 1:1 year event). The duration of this event should be the relevant critical duration for the runoff to the tree pit.

The tree soils can be designed using the same principles as bioretention systems described in **Chapter 18**. Many trees are able to remove a wide variety of pollutants from soil (USDA, 2006) including metals, pesticides and organic compounds. Excess nitrogen and phosphorus in soils are quickly taken up by trees with oxygen-rich rhizospheres, because osmosis can happen freely. Robust resilient trees can also metabolise contaminants (heavy metals, inorganic and organic compounds) into their carbon-rich heartwoods, removing them from the runoff.

Hydrocarbons tend to be trapped and degraded in the upper few centimetres of soil. Therefore, their removal will be more efficient where runoff is directed onto the surface of the soils and where this surface is well exposed to sunlight. A depth of engineered soil suitable for tree growth has been demonstrated to remove 70–85% of heavy metal loadings (Xiao and McPherson, 2008).

The acceptability of allowing infiltration from the tree pit will depend on the extent of the likely runoff contamination and the capability of the filtering soils to remove pollution (see **Chapter 4, Table 4.3**). It is likely to be similar to bioretention systems, provided the design is undertaken in an equivalent way.

19.6 AMENITY DESIGN

To deliver maximum amenity benefits (**Section 19.1**), the location and type of tree planting should be planned and designed as a key part of landscape and built environment delivery.

Trees should be selected and planted to maximise their potential delivery of surface water management objectives, but also so that they have a positive visual impact on the urban environment, with wide-ranging seasonal interest. The implementation of trees for surface water runoff management should be integrated with the delivery of green street and green infrastructure strategies, transport (including walking, cycling and highways) strategies and with the overall urban design strategy.

Canopy size and tree growth rate have been shown to have a strong influence on the cooling performance of trees and cooling objectives are best achieved through:

- setting canopy cover targets rather than driving design and management decisions on the basis of a number of trees
- providing non-compacted rooting environment(s) of sufficient size to achieve and sustain the desired canopy cover target
- ensuring a good supply of water, particularly during extended heatwaves (TDAG, 2014).

BOX 19.2 Performance of trees in removing phosphorous and nitrogen

A study of the nutrient removal performance of bioretention systems planted with trees in Australia (Denman *et al*, 2011) found that the inclusion of trees resulted in reductions of soluble nitrogen and phosphorous compared to unplanted control soils. A mix of deciduous and evergreen trees was used in the study, and came from a range of climates and environments. The removal of phosphorous was variable, and improved as the trees became more established over time. A reduction in concentration of 70–80% was achieved and, once stabilised, there was little difference in phosphorous removal between soils of different permeability. Nitrogen was produced by the planted systems during warmer months (output in leachate was greater than input) but overall the load was reduced and the concentration over time was reduced by 2–78%. The performance of tree pits in removing nitrogen was better with low hydraulic conductivity soils (4 mm/h) when compared to the medium and high permeability soils (95 mm/h and 170 mm/h respectively). However, 4 mm/h is unusually low for a bioretention soil and is likely to cause problems with water filtering through it in the long term. Tree species was not a significant factor in the performance of the systems with evergreen and deciduous trees giving similar results even during winter.

Trees placed close enough to directly shade buildings (called shade-effect trees) can lower summertime energy demand to cool a building. Care is then required to avoid blocking warm radiation during winter months, while shading sun-exposed walls during the summer. At UK latitudes, this is best achieved by positioning trees along the west-facing side of a building. Trees located such that they do not provide shade, but are close enough to influence the local microclimate, are termed climate-effect trees. These trees cool the local microclimate through evapotranspiration, leading to summertime air-conditioning energy savings. Climate-effect trees, particularly evergreen species, can also reduce heat loss from buildings in winter by reducing wind speed and thus air infiltration into the building (TDAG, 2014).

Figure 19.14 Popular benches around trees in Norwich (courtesy Anne Jaluzot)

19.7 BIODIVERSITY DESIGN

Trees can play a critical role in enhancing urban wildlife. The potential contribution of trees to local biodiversity strategies and habitat connectivity should be fully considered. Trees can act as bridges, maintaining connectivity for species through the urban landscape. Trees support wildlife in urban environments in many ways, providing food, shelter and habitat for birds, invertebrates and other species. The selection and mix of tree species will influence the habitat diversity that is provided. However, it is the canopy volume that is the best predictor of species use, as most animals require a minimum amount of canopy for survival (TDAG, 2014). A secondary consideration is the spatial arrangement of the canopy, as some species cannot cross large gaps readily or rely on tree lines for navigation, as is the case for some bats (Limpens and Kapteyn, 1991).

Strategies to enhance the wildlife benefits associated with trees in hard landscapes include:

- optimising tree location and planting patterns in the wider landscape context so as to increase habitat connectivity between vegetated areas, parks, groups of trees etc
- creating several layers by using shrubs and smaller trees, such as hazel, among taller trees and planting the opening of the tree planting hole with ground cover – this will, however, also increase the demands for water, so higher-density planting should be evaluated carefully to ensure that there is likely to be sufficient water supply
- incorporating nectar and fruit trees within the species selection, while considering the issues associated with fruit dropping, and the suitability of such species in hard surfaced areas (TDAG, 2014).

Native species are particularly good for supporting wildlife in urban areas. However, building ecological value and resilience is crucial. Enhancing ecological resilience to diseases and climate change requires a highly diverse local tree population and the risk of widespread damage can be reduced by diversifying the gene pool of new trees and by drawing from a wide-ranging planting list featuring both natives and non-natives suitable to different types of urban settings (TDAG, 2012).

19.8 PHYSICAL SPECIFICATIONS

There are many different types of tree structures available, but the key issues to consider when specifying tree pits, planters and structural soils are:

- designing the system so that the system drains water effectively, and the tree roots do not become waterlogged
- designing the system so that compaction of the soils around the tree roots cannot occur
- specifying the soil in which the tree roots will grow, to ensure healthy trees
- specifying the volume of the tree pit/soil.

The key requirements for tree pits, planters and structural soils are shown in **Figure 19.15**.

19.8.1 Soil specification

This is discussed in **Section 19.9**.

19.8.2 Soil volumes

Trees need large volumes of soil to allow them to grow to full height and be healthy. Ideally, a tree would be provided with unlimited soil volume, but this is clearly not practical, although tree soil volumes should be connected where practical to maximise space availability to roots. Green (2010) suggests that 0.056 m^3 of tree soil is provided for every 0.093 m^2 of tree canopy (at the mature height).

McPherson and MacDonagh (2012) summarised the policies of a number of US states and towns and compared them with the minimum volume suggested by research studies. This research supports the adoption of minimum rooting volumes for trees at the higher end of the ranges suggested by local implementation policies. It suggests that trees with 75 cm trunk diameters require at least 40 m^3 soil volume. Smaller diameter trees will need slightly less, but this will be dependent on tree species.

Tree pit manufacturers can provide further guidance on minimum volumes required.

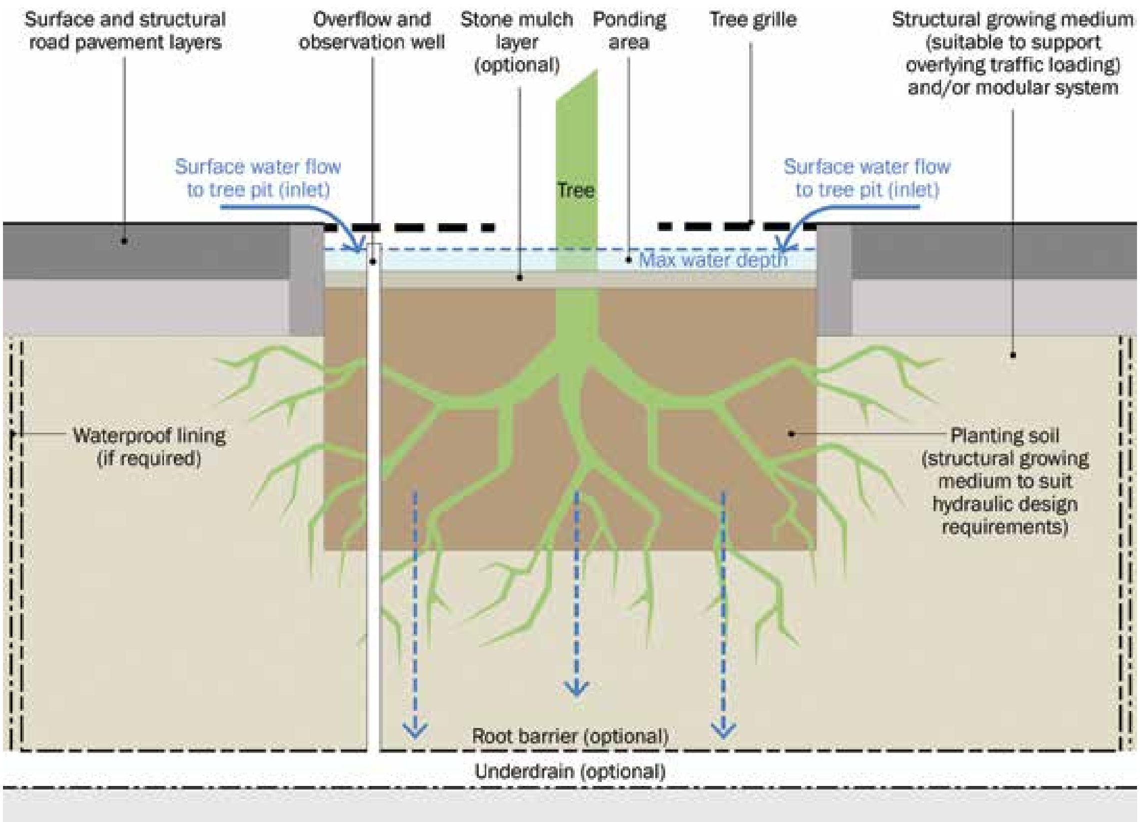

Figure 19.15 Key details of tree structures

19.8.3 Pre-treatment and inlets

Surface water runoff can be introduced to a tree pit or tree soil in a variety of ways. Conveyance collector channels or rills can be directed to spill onto the tree soil surface; impermeable surfaces can be sloped towards the tree pit; or permeable surfaces can be used to collect and convey the runoff in subsurface media layers. Example layouts are shown in **Figure 19.16**.

Figure 19.16 Examples of inlets to allow surface water runoff to infiltrate into tree pits (courtesy Anne Jaluzot and Dŵr Cymru Welsh Water)

19.8.4 Outlets

Tree pits need to be well drained. This can be achieved by infiltration to the ground if soil conditions are suitable. If infiltration is not possible then an outfall to the surface water drainage system will be required. The outlet should be set at a level to maintain the required maximum water level in the base of the tree pit. Outlets from the base of tree soils should have a large surface area and will normally comprise perforated pipes, geocomposites or geocellular units that are connected to pipes.

Where water is allowed to infiltrate into the surrounding soil it should be prevented from flowing into any adjacent normal sub-base construction below pavements. If the head driving the water is not very great (eg from a planar area of structural soils) water migration into the adjacent sub-base may not be a big risk. If the risk is considered unacceptable, water migration to the sub-base should be prevented, for example using a geomembrane.

19.9 MATERIALS

There are various specifications for structural growing media that have been used successfully around the world. The specification should take account of local climate and tree species, and guidance should preferably be sought from an arboriculturist or horticulturalist. When using proprietary products, the recommendations provided by the manufacturer should always be followed.

19.9.1 Soil for use in modular and raft systems

The main requirements of the soil for use in modular structures and rafts are that:

- the texture of the soil should be homogeneous throughout the whole profile – there should not be any great differences between different layers
- the soil should be well graded
- the soil should have an appropriate humus content (about 5%)
- the soil should have a permeability within a sufficient range – high enough to drain effectively, but low enough so that the water is treated as it filters through – typically this will be 100–300 mm/h.

Figure 19.17 Planting beds protect existing mature trees and provide seating, Islington, London (courtesy Liz Kessler)

An example specification developed for the UK is provided in **Box 19.3**, but it is possible to develop other bespoke specifications (eg Schröder, 2013). A key requirement is that the materials should be available locally at reasonable cost.

Tree soils should not be overly compacted and should be 75–80% of maximum dry density (McPherson and MacDonagh, 2012).

BOX 19.3 **Example specification for soil to provide rooting environment in modular structures and rafts**

Topsoil for use in modular structures and rafts

Topsoil shall comply with BS 3882:2007 and have permeability within the range specified by the designer.

Soil for use in modular structures and rafts

All soil materials shall be:

- free of pests and disease that would render the soil unsuitable for horticultural use
- reasonably free from non-soil material, brick and other building materials, and free from wastes, sharps, hydrocarbons, plant matter, weed roots, stolons, rhizomes and any other foreign matter or material or substance that would render the soil unsuitable for horticultural use
- free of materials that are:
  - corrosive
  - explosive or flammable
  - hazardous to human or animal life
  - detrimental to healthy plant growth.

The tree soil shall meet the requirements in **Table 19.1**.

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BOX 19.3 **Example specification for soil to provide rooting environment in modular structures and rafts**

Table 19.1 Specification for soil appropriate for use in modular structures and raft systems

Parameter	Unit	Lower limit	Upper limit
Clay and silt (< 0.063 mm) Note: particle size distribution (PSD) to BS 1377-2:1990 PSD may also be presented as a grading curve[1]	%Vol	15	30
Sand (0.063–2.0 mm) of which at least 70% of the sand fraction shall fall into medium sand to coarse sand (0.25–1.0 mm) range Note: PSD to BS 1377-2:1990 PSD may also be presented as a grading curve[1]	%Vol	70	85
Stones – fine to medium gravel (2–20 mm)	%Vol	–	–
Stones – coarse gravel and cobbles (> 20 mm)	%Vol	–	–
Saturated hydraulic conductivity with the sample compacted to 85% of maximum dry density using the standard proctor test, ASTM D698-12e2 (kSat)	mm/hr	25	115
pH value BS EN 13037:2011	pH unit	5.5	7.5 (or as high as 8.5 or to which the plantings specified are pH tolerant, whichever is more neutral)
Electrical conductivity (1:2.5 water extract) BS EN 13038:2011	µS/cm	—	1500
Organic matter BS EN 13039:2011	%DW	3	5
Extractable phosphorus BS EN 13652:2001	mg/l	12	36
Calcium carbonate	%	—	—

Note

1 Particle size distribution for soils in modular structures and rafts.

PSD is of secondary importance compared with saturated hydraulic conductivity. A material whose PSD falls within the following recommended range does not preclude the need for hydraulic conductivity testing; that is, it does not guarantee that the material will have a suitable hydraulic conductivity. However, the grading in **Table 19.1** provides a useful guide for selecting an appropriate material. The grading needs to be readily understood by both drainage and landscape/horticultural professionals as each uses a different standard format for presenting grading information. The grading in **Table 19.2** is for the same material specified in **Table 19.1** but presented in a standard engineering format.

Table 19.2 Example grading for soil appropriate for use in modular structures and raft systems

Sieve size (mm)	% passing
2.0	100
0.2	40–50
0.063	15–30

19.9.2 Structural growing media

A good structural growing medium will have known water-holding, drainage, structural and load-bearing characteristics (Day *et al*, 2008). It should be able to still support plant growth when compacted to 95% of standard Proctor density. It should also be supported by the results of field trials that demonstrate its performance. A key requirement is that the materials should be available locally at reasonable cost. An example specification for structural soil is given in **Box 19.4**.

BOX 19.4 Example specification for structural soil (from Day *et al*, 2008)

Structural soil is a uniformly blended mix of crushed stone, clay loam and, if required, hydrogel. The constituents should be mixed to the following proportions:

- crushed stone: 80 kg dry weight
- loam: 20 kg dry weight
- hydrogel: 0.03 kg dry weight per 100 kg crushed stone
- total moisture: place at optimum moisture content as determined in compaction tests to BS 1377-4:1990

Crushed stone

Angular crushed rock of granite, limestone or similar

Grading (PSD to BS 1377-2:1990)

Sieve size	% passing (by mass)
40 mm	90–100
28 mm	20–55
20 mm	10

Sieve size adapted to suit British/European Standard sizes

A ratio of nominal maximum to nominal minimum particle size of 2 is required

Acceptable aggregate dimensions should not exceed 2.5:1.0 for any two dimensions chosen

Minimum 90% with one fractured face, minimum 75% with two fractured faces

Resistance to fragmentation, LA: < 40%

Magnesium sulphate soundness: < 18%

Clay loam

Clay loam based on USDA classification system

Uniform composition, free of stones greater than 12.5 mm, lumps, plants, roots, debris or other extraneous matter; it shall not contain substances harmful to plant growth or human health

Nutrient levels as required for the types of plants to be grown

Organic matter content: 2–5% by dry weight

pH: between 6.0 and 7.6

Soluble salt: less than 1.0 millimho per cm

Cation exchange capacity: > 10

Carbon:nitrogen ratio: < 33:1

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BOX 19.4 Example specification for structural soil (from Day *et al*, 2008)

Proportion of particles (PSD to BS 1377-2:1990)

Gravel (+2 mm)	< 5%
Sand (0.063–2 mm)	20–45%
Silt (0.0002–0.063 mm	20–50%
Clay (< 0.002 mm)	20–40%

Note
Particle size limits are based on USA classification.

Hydrogel

Shall be a potassium propenoate-propenamide copolymer hydrogel or similar.

Mixing

The soil should be mixed using suitable equipment to provide a uniform and consistent material.

The structural soil should not leach pollutants into the surface water.

The type of stone used in the mix (whether limestone, granite, lava rock or other stone) will influence the pH of the soil and soil water. In systems that incorporate concrete products, the pH will continue to rise over time as concrete deteriorates. In some cases, the addition of chemicals may be necessary to help offset pH conditions, if required by the trees selected for the site. These chemicals should be selected so as to not damage the concrete or other materials. Designs should consider this aspect of long-term maintenance and try to minimise these effects (TDAG, 2014).

Soils used in tree pits and structural soils should be tested and approved as part of a quality assurance programme to ensure that materials meeting the specification are used on site. Suggested details are provided in **Box 19.5**.

19.10 LANDSCAPE DESIGN AND PLANTING

The inclusion of trees as part of the surface water management strategy requires full integration with the landscape and architectural design of a new development to ensure that the benefits are maximised and the trees enhance and support building and landscape performance. The size, species, characteristics and planting location should be guided by a landscape designer, with advice from an arboriculturist where required.

- Guidance on species selection, planting strategies etc is provided in TDAG (2012, 2014).
- Landscape design and planting best practice is presented in detail in **Chapter 29**.

BOX 19.5 Testing and approval of tree soils and structural soils

Programme for sourcing soil

Sufficient time should be allowed for sourcing and testing the proposed soil(s) to meet the requirements of the soil specification.

Typically at least four weeks is recommended for sourcing soils, so that the necessary testing can be undertaken to demonstrate compliance with the specification.

The contractor shall provide soil laboratory test certificates to the contract administrator for review and approval.

Sampling protocol

The soil(s) to be considered for use should be sampled before placement and preferably while stockpiled at its source or manufacturer's location.

The sample(s) shall be representative of the soil to be used. One composite sample shall be taken for every **500 m³** of each type of soil to be used.

Each composite sample should be made up of **10 No. subsamples** taken from evenly spaced locations across the stockpile/field. The subsamples shall be mixed together and quartered down to form a 5 kg composite sample.

Each composite sample shall be placed in a clean, strong plastic bag, each labelled with the source reference and date of sampling. Other samples may be required in different containers for specific analyses (eg organics).

Soils of different types should not be mixed to form a composite sample.

Soil testing facilities

Soil samples shall be sent to a soil science testing facility (eg UK Accreditation Service (UKAS) and/or EA Monitoring Certification Scheme (MCERTS) accredited) with a request for each sample to be analysed in accordance with the schedule provided in the specification.

19.11 CONSTRUCTION REQUIREMENTS

If sediment from construction work accumulates on the exposed surface of a tree pit or planter, it should be cleared and the pit fully rehabilitated before the drainage system is adopted by the organisation responsible for carrying out the maintenance.

It is important that the tree soils and structural soils are not damaged by inappropriate handling or compaction during construction. The soil should be placed when it is non-plastic (friable) in consistency with a moisture content at least 5% below the soil's plastic limit. It should not be placed if is frozen or during heavy rainfall.

The tree soil and structural soil should be not be allowed to become mixed with other material such as sub-base or demolition debris. Handling the soil can destroy its structure, and so multiple handling should be kept to a minimum. It is vital that once placed, the soil is not compacted by trampling or trafficking by site machinery.

The use of additional slow release fertilisers in the topsoil may be required (as advised by the tree specifier) to help tree establishment. The risk of this causing surface water pollution has to be weighed against the risk of the tree dying, but the use of fertilisers should be avoided wherever possible as they add nutrient load to the surface water.

Structural soils are load-bearing and form part of the sub-base construction to pavements. They should be compacted to a suitable density as defined by the pavement designer. Roots can still penetrate the materials because the density that roots can tolerate is dependent on the particle size distribution of the soils they are in.

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety guidance is provided in **Chapter 36**.

19.12 OPERATION AND MAINTENANCE REQUIREMENTS

Maintenance requirements of trees will be greatest during the first few years, when the tree is becoming established. Early maintenance should involve regular inspection, removal of invasive vegetation and possibly irrigation during long dry periods, particularly in soils with high void ratios. Tree roots need to establish good root–soil contact before they can efficiently extract water from the soil. The expertise of a arboriculturist/landscape architect with local knowledge should be sought regarding appropriate irrigation schedules. Maintenance responsibility for a tree pit or planter should always be placed with an appropriate organisation.

Table 19.3 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

TABLE 19.3 Operation and maintenance requirements for trees (after CRWA, 2009)

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Manage other vegetation and remove nuisance plants	Monthly (at start, then as required)
	Inspect inlets and outlets	Inspect monthly
Occasional maintenance	Check tree health and manage tree appropriately	Annually
	Remove silt build-up from inlets and surface and replace mulch as necessary	Annually, or as required
	Water	As required (in periods of drought)
Monitoring	Inspect silt accumulation rates and establish appropriate removal frequencies	Half yearly

Sediments excavated from a tree pit or planter that receive runoff from residential or standard road and roof areas are generally not toxic or hazardous material and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For runoff, from busy streets with high vehicle traffic sediment testing will be essential.

▶ Further detail on waste management is provided in **Chapter 33**.

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the tree pits/planters should be monitored and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 31**.

Many of the specific maintenance activities for trees can be undertaken as part of a general landscaping or specific tree maintenance contracts.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is provided in **Chapter 36**.

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STATUTES

Regulations

Construction (Design and Management) Regulations (CDM) 2015

British Standards

BS 8545:2014 *Trees: from nursery to independence in the landscape*

BS 5837:2012 *Trees in relation to design, demolition and construction. Recommendations*

BS 3882:2007 *Specification for topsoil and requirements for use*

BS 1377-2:1990 *Methods of test for soils for civil engineering purposes. Classification tests*

BS 1377-4:1990 *Methods of test for soils for civil engineering purposes. Compaction-related tests*

BS EN 13037:2011 *Soil improvers and growing media. Determination of pH*

BS EN 13038:2011 *Soil improvers and growing media. Determination of electrical conductivity*

BS EN 13039:2011 *Soil improvers and growing media. Determination of organic matter content and ash*

BS EN 13652:2001 *Soil improvers and growing media. Extraction of water soluble nutrients and elements*

USA Standards

ASTM D698-12e2 *Standard test methods for laboratory compaction characteristics of soil using standard effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))*

Image courtesy Robert Bray Associates

20 PERVIOUS PAVEMENTS

Contents

Chapter 20

Pervious pavements

This chapter provides guidance on the design of pervious pavements – pavements that are suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into underlying structural and foundation layers.

- ▶ *Appendix C, Section C.5.1 demonstrates how to design an infiltrating pervious pavement for a residential area.*
- ▶ *Appendix C, Section C.5.3 demonstrates how to design a lined pervious pavement for a supermarket.*

20.1 GENERAL DESCRIPTION

Pervious pavements provide a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into the underlying structural layers. The water is temporarily stored beneath the overlying surface before use, infiltration to the ground, or controlled discharge downstream (**Section 20.1.9**).

Pervious surfaces, together with their associated substructures, are an efficient means of managing surface water runoff close to its source – intercepting runoff, reducing the volume and frequency of runoff, and providing a treatment medium. Treatment processes that occur within the surface structure, the subsurface matrix (including soil layers where infiltration is allowed) and the geotextile layers include:

- filtration
- adsorption
- biodegradation
- sedimentation.

There are two types of pervious pavements that are defined on the basis of the surfacing materials:

Porous pavements infiltrate water across their entire surface material, for example reinforced grass or gravel surfaces, resin bound gravel, porous concrete and porous asphalt.

Permeable pavements have a surface that is formed of material that is itself impervious to water. The materials are laid to provide void space through the surface to the sub-base (eg standard concrete block paving is specifically designed to allow rainwater falling onto the surface or runoff discharged over the surface to infiltrate through the joints or voids between the blocks into the underlying pavement structure).

The main types of surfaces used as part of pervious pavement construction are:

- modular permeable paving
- porous asphalt
- grass reinforcement
- resin bound gravel
- porous concrete

- macro pervious
- sports surfaces
- block porous paving.

These are summarised in **Sections 20.1.1 and 20.1.8.**

20.1.1 Modular permeable paving

The most common surface is concrete block permeable paving, but other modular surfacing materials can also be used (clay pavers, natural stone etc).

All types of surface have widened joints filled with grit to allow water into the underlying bedding layer and sub-base.

Potential uses include:

- pedestrian areas
- private driveways
- car parks
- lightly to heavily trafficked roads
- ports.

The common layout is to use modular permeable pavement for car park spaces and normal asphalt lanes between (**Figure 20.1**). This is to reduce costs and also because the asphalt can tolerate turning forces more effectively. The sub-base storage layer extends below the asphalt.

There are also spacer systems available that allow the use of normal paving slabs as permeable surfaces (with appropriate free draining joint, bedding and sub-base material). These are best suited to areas with only pedestrian traffic.

Figure 20.1 Park and ride scheme on the outskirts of Cambridge using concrete block permeable paving (courtesy EPG Limited)

Figure 20.2 Private driveway using natural stone as permeable paving (courtesy The Ethical Stone Company/ SteinTec)

20.1.2 Porous asphalt

Porous asphalt can be used as an independent surface or to provide a stronger base to concrete block permeable pavements where it is to be trafficked frequently by trucks. Porous asphalt surfacing reduces traffic noise.

Potential uses include:

- car parks
- private driveways
- lightly trafficked roads
- playgrounds
- schools.

Figure 20.3 shows porous asphalt surfacing being used for a car park at East Midlands Airport. The storage below the car park has been increased using 150 mm thick geocellular sub-base replacement units that comply with BS 7533-13:2009.

Figure 20.3 Car park at East Midlands Airport with porous asphalt surfacing (courtesy EPG Limited)

20.1.3 Grass reinforcement

Grass reinforcement uses plastic or concrete grids infilled with grass or gravel.

This type of pavement is most suitable for lightly trafficked locations, especially where it only has seasonal use, so that the grass has time to recover.

Potential uses include:

- overflow car parks to leisure facilities
- schools
- private driveways
- hotel and office car parks
- fire access or other infrequent HGV traffic.

It is important that these systems are well constructed to ensure that the soils are not compacted. The type of grass needs to suit the local climate.

Figures 20.4 and 20.5 provide examples of plastic grids and concrete grids respectively.

Figure 20.4 Plastic grids at Lake Garda, Italy (courtesy EPG Limited)

Figure 20.5 Concrete grids in a park and ride overflow car park, Gwynedd (courtesy EPG Limited)

20.1.4 Resin bound gravel

Resin bound gravel provides a wide range of finish colours, which makes it attractive for use in public, recreational spaces (**Figure 20.6**).

This type of pavement is most suitable for lightly trafficked locations.

Potential uses include:

- schools
- pedestrian areas around buildings or precincts
- private driveways.

Figure 20.6 Construction of pavement using resin bound post consumer recycled glass aggregate (courtesy Filterpave Limited)

Figure 20.7 Retail development car park with porous concrete, High Wycombe (courtesy EPG Limited)

20.1.5 Porous concrete

Porous concrete can be used as a surfacing material or to provide improved structural stability to the base of concrete block permeable pavements where it is to be trafficked frequently by trucks.

Potential uses include:

- car parks
- lightly trafficked roads.

Figure 20.7 shows a large (2800 m^2) parking area constructed with porous concrete to meet the sustainable drainage planning requirements for a new retail development site. The porous concrete surface has been used in the parking bays, traffic aisles and the access route into this area of parking. In other parts of the site it has been used only in parking bays with the impermeable asphalt aisles draining onto the porous concrete.

20.1.6 Macro pervious paving

Macro pervious systems are where normally impermeable surfaces are drained to channels or other collection systems designed to trap oil and silt.

This approach allows water storage in the sub-base below impermeable surfaces in areas where there are high traffic loads and/or high shear forces from turning vehicles (Chaddock and Nunn, 2010).

The example of a macro pervious pavement shown in **Figures 20.8 and 20.9** uses a treatment channel to collect runoff, and this discharges to an open-graded blanket of sub-base (the same materials as used below concrete block permeable paving) or geocellular sub-base replacement below the impermeable surfacing. Other options for discharge to the drainage layer could be considered such as via a bioretention system. Whatever approach is used, the main requirement is that robust treatment and removal of silt is required before discharge into the sub-base.

This type of paving serve for all types of uses, as long as the site is not subject to very high silt loads and where regular maintenance can be assured.

Figure 20.8 Macro pervious pavement under construction in the Midlands – kerb drain collector/ pollution trap with connectors before placing diffusers and permeable sub-base to left (courtesy Phil Tomlinson)

Figure 20.9 Macro pervious pavement in warehouse yard in north-west England with channel collection/ pollution trap and concrete pavement construction (courtesy EPG Limited)

20.1.7 Sports surfaces

Either aggregate sub-base or plastic sub-base replacement units can be used below turf or porous artificial surfaces to manage surface water runoff for multi-use games areas, sports pitches and play areas.

These surfaces can be used as part of a water management system where the water is stored for irrigation or other use. Some systems include passive irrigation where water is lifted up from the storage layer into the overlying surface by capillary action.

Figure 20.10 Construction of sports drainage and attenuation layer below school sports pitch in Hull (courtesy Phil Tomlinson)

Figure 20.11 Construction of attenuation and irrigation system used below equestrian surfacing (courtesy Andrew Bowen)

20.1.8 Block porous paving

Concrete (or other recycled materials such as glass) block porous paving relies on water permeating through the porous paving unit material rather than through widened joints. Experience in the UK indicates that they are much more prone to clogging than any of the other types of system, due to very small size of the voids in the surface of the paving unit. Therefore, their potential use is limited due to this risk of clogging.

20.1.9 Systems of water management

There are three principal systems of water management below the surface of pervious pavements that are described in **Figures 20.12 to 20.14**.

Type A (**Figure 20.12**) reflects a system where all the rainfall passes into the substructure (where it may be stored temporarily) from where it infiltrates into the soil beneath. Normally, there will be no discharge from the system to a sewer or watercourse. However, an emergency overflow may be required to cater for events in excess of the design event or to allow for the system becoming less efficient (ie infiltration rates reducing) over its design life.

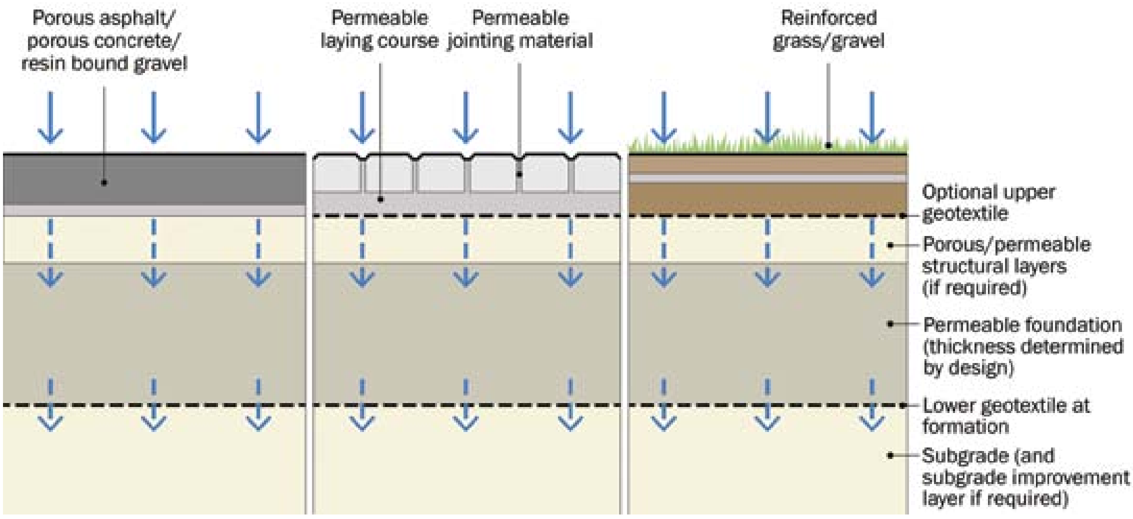

Figure 20.12 Pervious pavement system types: Type A – total infiltration

In a Type B system (**Figure 20.13**), the proportion of the rainfall that exceeds the infiltration capacity of the subsoils flows to the receiving drainage system. This can occur by direct drainage through the sub-base or by conveyance via perforated pipes within or below it. Geocomposite blankets can also be used to collect and convey water below the sub-base layer or can be placed vertically at the edges of the construction to allow connection to a pipe. By preventing the build-up of water above the subgrade, the risks to soil stability are reduced.

There is no infiltration with a Type C system (**Figure 20.14**). The system is generally wrapped in an impermeable, flexible membrane placed above the subgrade (formation level). Once the water has filtered through the sub-base, it is conveyed to the outfall via perforated pipes or fin drains. This can be used for situations where:

- soils have low permeability or low strength (and could therefore be damaged by the introduction of infiltrating water)
- the water is to be harvested and used
- the underlying groundwater is sensitive and requires protection
- the water table is within 1 m of the sub-base
- the site is contaminated and the risks of mobilising contaminants must be minimised.

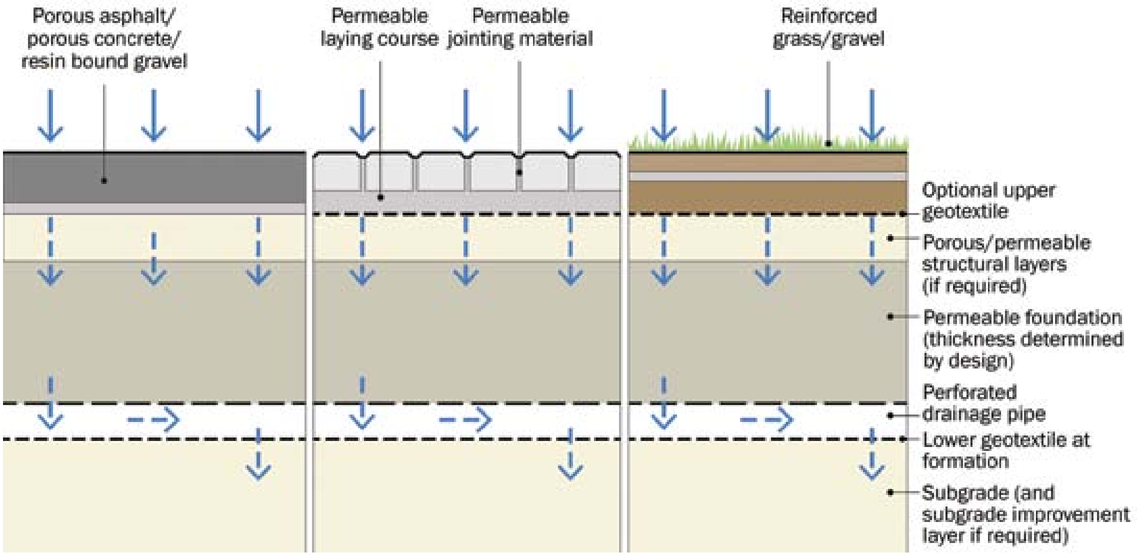

Figure 20.13 Pervious pavement system types: Type B – partial infiltration

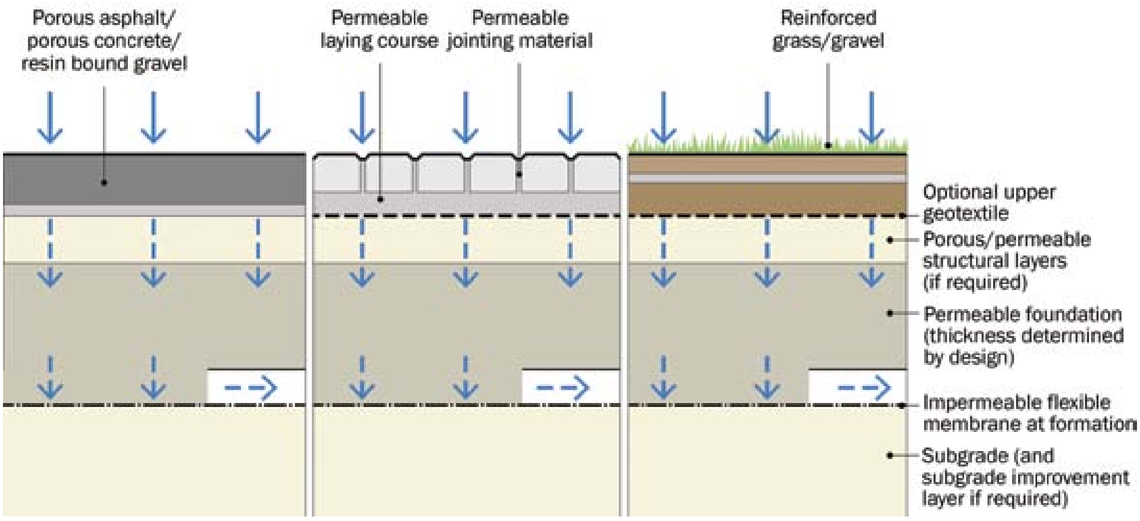

Figure 20.14 Pervious pavement system types: Type C – no infiltration

Variations of these three basic types of pervious pavement construction include the following:

- Grass reinforcement systems can be used over standard pavement materials (eg Type 1 sub-base). These systems will provide Interception, but attenuation and treatment of the residual runoff from the surface will still be required, as they do not provide for any storage of water in the sub-base.
- Impermeable asphalt or concrete surfacing used over permeable sub-base (known as macro pervious surfaces [MPPS], or reservoir pavements) where the water is introduced into the storage in the sub-base via a series of distinct entry points – fast enough to prevent flooding during the design storm but without allowing silt and debris to enter the sub-base. The system offers the opportunity to accrue the benefits of a pervious pavement when the use of traditional paving surfaces is the preferred option due to traffic considerations. The performance of the silt trapping devices is crucial in this application as it is impossible to subsequently remove silt from the sub-base without complete system reinstatement. Simple catch pits or normal channels are not suitable.

20.2 GENERAL DESIGN CONSIDERATIONS

There is a range of surfacing materials that can be used to allow water to soak into the underlying sub-base. The choice of the most appropriate surfacing for a given location is crucial to the successful use of pervious pavements to manage surface water. This will mainly be based on the expected traffic loadings and the visual appearance that is required.

Type C system (**Section 20.1.9**) designs may be modified to allow a proportion of runoff to be stored and used for various non-potable applications such as irrigation, toilet flushing etc (**Figure 20.15** and Beecham *et al*, 2010). Because of the evaporation occurring, the proportion of runoff captured by a pervious pavement system is lower than from an impermeable surface, and it is recommended that runoff coefficients of 40% are used for rainwater harvesting design (Interpave, 2010).

▶ For further information on opportunities for using rainwater, see **Chapter 11** and Leggett *et al* (2001a, 2001b).

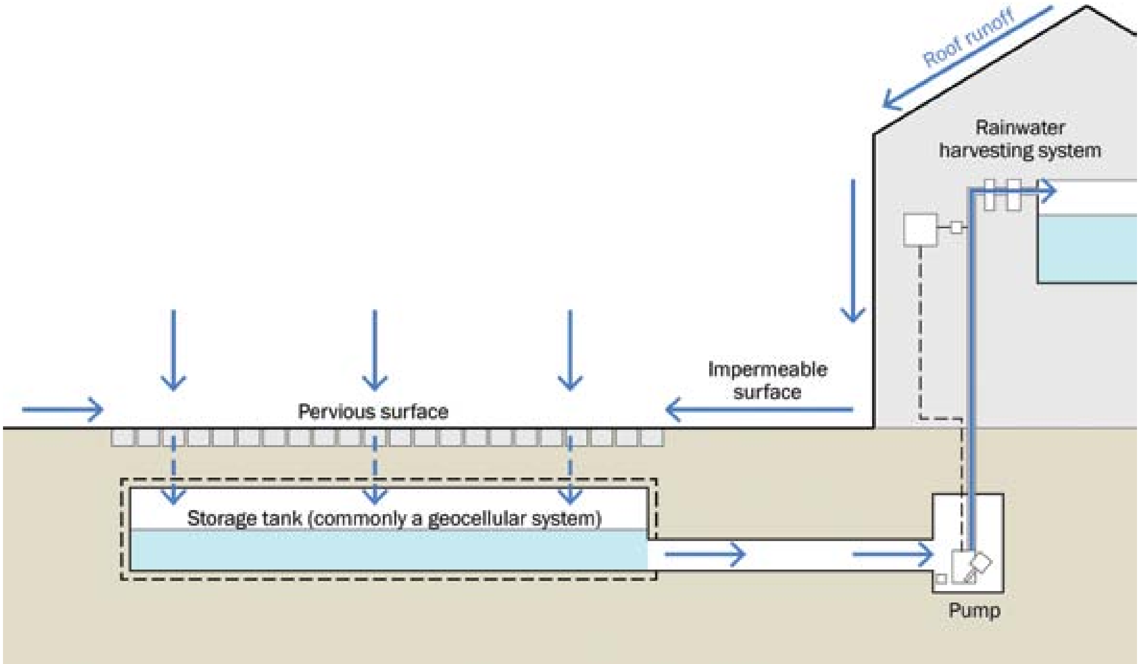

Figure 20.15 Example of rainwater harvesting system (from Interpave, 2010)

The aggregate sub-base in pervious pavements can sometimes be replaced with geocellular sub-base replacement systems (**Chapter 21**). These will provide a higher storage capacity (with > 90% porosity), but consideration will need to be given to the use of geotextile layers to ensure adequacy of treatment of the runoff (**Section 20.6**). The use of geocellular structures beneath paving systems exposes them to very high loads. Module elastic deformation and the strength of joints between modules are critical to the performance of the overlying layers of blocks or asphalt, and careful design will be required.

▶ Further advice on using geocellular structures is provided in **Chapter 21**.

Pervious pavements are generally used to manage rainfall landing directly on the surface, but their capacity is such that they are often also used to manage runoff draining from adjacent areas, such as roofs or adjacent impermeable areas of car parks. If an adjacent impermeable area is draining onto the surface of the pervious pavement, the maximum ratio should be 2:1 (impermeable:pervious) to minimise the risk of silt

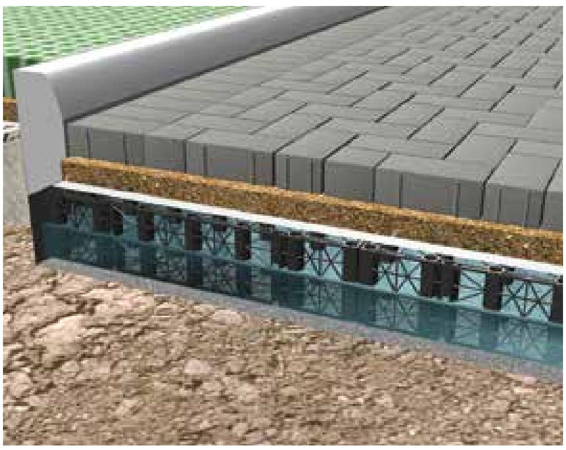

Figure 20.16 Concrete block permeable paving with geocellular sub-base replacement system (from Interpave, 2013)

completely blocking the pavement surface. Where pavements are draining adjacent impermeable areas, clogging will initially develop close to the impermeable pavement and a clogging front will gradually migrate across the pervious pavement.

Roof drainage can direct large volumes of water into the pavement very quickly, and inlet diffusers may be required to regulate the flow velocities (**Section 20.10.1**). These require very careful design, especially where syphonic drainage is discharging into the pavement. Where water from roofs is directed via catch pits directly into the sub-base the ratio of impermeable:pervious above does not apply. For smaller areas of roof it is possible to discharge the downpipe directly onto the pavement, in which case the maximum ratio of 2:1 should still apply.

▶ Health and safety risk management design guidance is presented in **Chapter 36**.

20.3 SELECTION AND SITING OF PERVIOUS PAVEMENTS

Pervious pavements can be used on most sites, but they need to be used in appropriate locations. They can often be combined with other solutions such as detention basins, ponds and wetlands allowing these subsequent attenuation and treatment features to be shallower and smaller. The use of pervious pavement should be avoided where there is a high risk of silt loads on the surface.

Pervious pavements are typically built as an alternative to impermeable surfaces and therefore require no extra development space for their construction. They require only a small head difference from the runoff surface to their outfall and can therefore be employed on very flat terrain.

Constructed pervious pavements tend to be used to drain highways with low traffic volumes and speeds (less than 30 mph), car parking areas and other lightly trafficked or non-trafficked surfaces. However, they are capable of supporting HGV traffic (Chaddock and Nunn, 2010, BS 7533-13:2009) and, in the UK, specific types of pervious pavements have been used successfully for surfaces with heavy axle load traffic. In the USA, there are isolated examples of successful use of pervious pavements on state highways, and they are currently looking at the use of pervious concrete design for heavily trafficked pavements (Wanielista and Chopra, 2007). Such pavements should be designed on an individual basis and in conjunction with manufacturers and experienced geotechnical and pavement engineers. They should have a stiff layer of asphalt, asphalt concrete, concrete or hydraulically bound coarse-graded aggregate below the bedding layer. The main concerns are the frequent vehicle braking and turning actions that can cause the surfaces to rut, concrete blocks to spread and porous asphalt to spall.

The acceptability of infiltration from a permeable pavement should be determined by following the guidance provided in **Section 25.2**, complying with all relevant requirements for infiltration systems with respect to ground stability, depth to water table etc and **Section 26.7** for the protection of groundwater.

Unlined pavements should not be used on brownfield sites unless it has been demonstrated that the risk posed by leaching of contaminants is managed to acceptable levels. Unlined pavements should not be used to treat runoff from areas with high contaminant loads if the risk of groundwater pollution due to infiltration is unacceptably high. Where infiltration is prevented, the seasonally high groundwater level should always be below the base of the pavement formation.

Pervious pavements can be used in most ground conditions and can be sited on waste, uncontrolled or non-engineered fill, if necessary with a liner, where the design allows for differential settlement. Unlined pavements should not be used in locations where infiltrating water may cause slope instability or foundation problems, for example areas of landslides, at the top of cutting or embankment slopes or close to building foundations unless a full assessment of the risks has been carried out by a suitably qualified geotechnical engineer or engineering geologist.

▶ For information on allowing infiltration close to buildings, see **Chapter 25**.

The effects of water storage on the structural capacity of the underlying soils should also be carefully assessed and slopes and collection systems used to manage these risks. There should always be a nominal fall on the pavement formation level.

Figure 20.17 gives guidance on soil classification, and **Table 20.1** recommends appropriate pavement systems for a range of subgrade conditions. Both are taken from Interpave (2010), but can be applied to any surfacing system, not just concrete block permeable paving (CBPP).

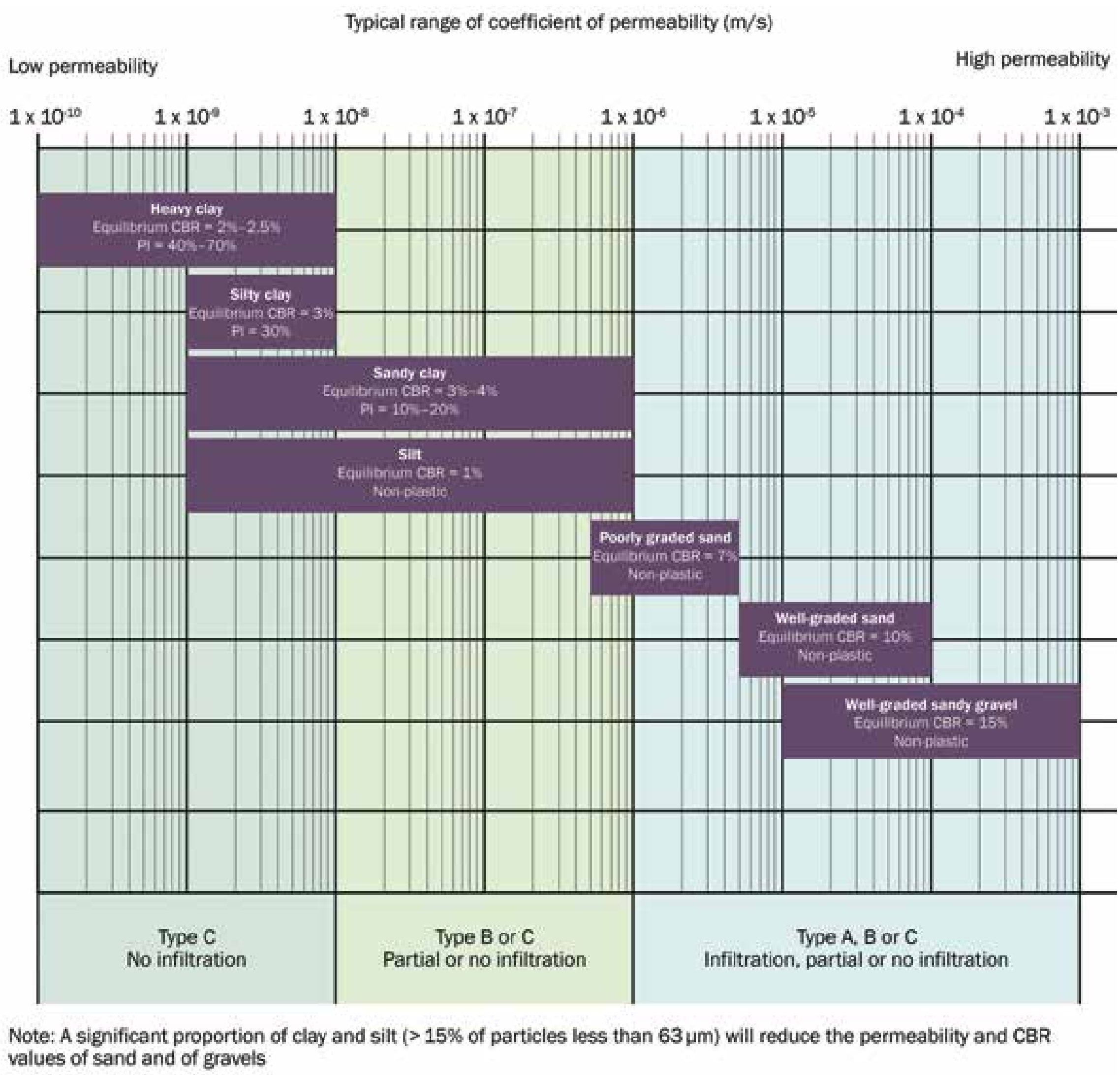

Figure 20.17 Soil classification guide (after Interpave, 2010)

The location of buried services should be taken into account in any design to ensure the long-term success of pervious pavement projects. Shallow services should, wherever possible, be located beneath areas of conventional impermeable surfacing (which drain to adjacent pervious areas), or within service corridors or verges, thus avoiding the pervious construction. Deeper surface and foul sewers can often pass below the sub-base formation layer. This approach will minimise the need to excavate through the pervious construction to access services.

Using an appropriate mix of permeable and impermeable surfacing can provide structure to the overall design layout – both visually and technically, helping designers realise aspirations promoted by DCLG (2007). For example, an impermeable central carriageway might be employed to contain services, visually differentiated from pervious parking bays. Alternatively, impermeable service crossings could also be used as pedestrian ways, clearly differentiated from pervious areas intended for vehicles.

TABLE 20.1 Guidance on selection of a pavement system type (after Interpave, 2010)

Ground characteristics		Type A: total infiltration	Type B: partial infiltration	Type C: no infiltration
Permeability of subgrade defined by coefficient of permeability k (m/s)	1×10^{-6} to 1×10^{-3}	✓	✓	✓
	1×10^{-8} to 1×10^{-6}	×	✓	✓
	1×10^{-10} to 1×10^{-8}	×	× (1)	✓
Highest expected water level within 1000 mm of formation level		×	×	✓
Pollutants present in subgrade		×	×	✓
Ground conditions such that infiltration of water is not recommended (solution features, old mine working etc, Chapter 8)		×	×	✓

Note

1 Partial infiltration systems may be used in soils with permeability less than 10^{-8} m/s but the infiltration of water is not allowed for in the storage design. This helps with the provision of Interception.

BOX 20.1 Units used for infiltration

The SI unit of reporting soil permeability is m/s. Therefore, soil infiltration rates are usually also reported in m/s. There is a general understanding within the industry of what constitutes a high or low value quoted in these units.

The infiltration rate of rainwater into the top surface of a pervious pavement is often compared to rainfall intensity. Rainfall intensity is reported in mm/h, and therefore the infiltration of water into the pervious pavement is reported in these units.

There is an extensive body of evidence demonstrating that pervious pavements perform adequately in cold climates. They tend to withstand freeze–thaw conditions well and tend to be less affected by frost heave than standard pavement surfacing (Lake County Forest Preserves, 2003; Kevern *et al,* 2009) due to the air in the aggregate base acting as an insulating layer limiting frost penetration into the pavement, coupled with the higher internal latent heat associated with the higher soil moisture content. Pervious pavements do not tend to ice on the surface because water and melting snow drain straight into the pavement rather than ponding before runoff. Pervious pavements also tend to thaw faster than normal pavements and thus require lower than average salt applications. Studies have also shown little loss in the treatment performance of pervious pavements during cold weather. However, they can develop a hoar frost on the surface more frequently than normal pavement construction.

20.4 OVERALL DESIGN REQUIREMENTS

Pervious pavements provide two functions.

1. They need to be able to effectively capture the design storm event and discharge it in a controlled manner to the subgrade or drainage system.
2. They need to provide sufficient structural resistance to withstand the loadings imposed by vehicles travelling on the surface.

Therefore there are two sets of calculations required, and the greater thickness of permeable sub-base from the two calculations is used as the design thickness. Pervious pavements generally require flow controls at the outlets to ensure effective use of the storage in the sub-base. A recommended design flowchart is provided in Figure 20.19.

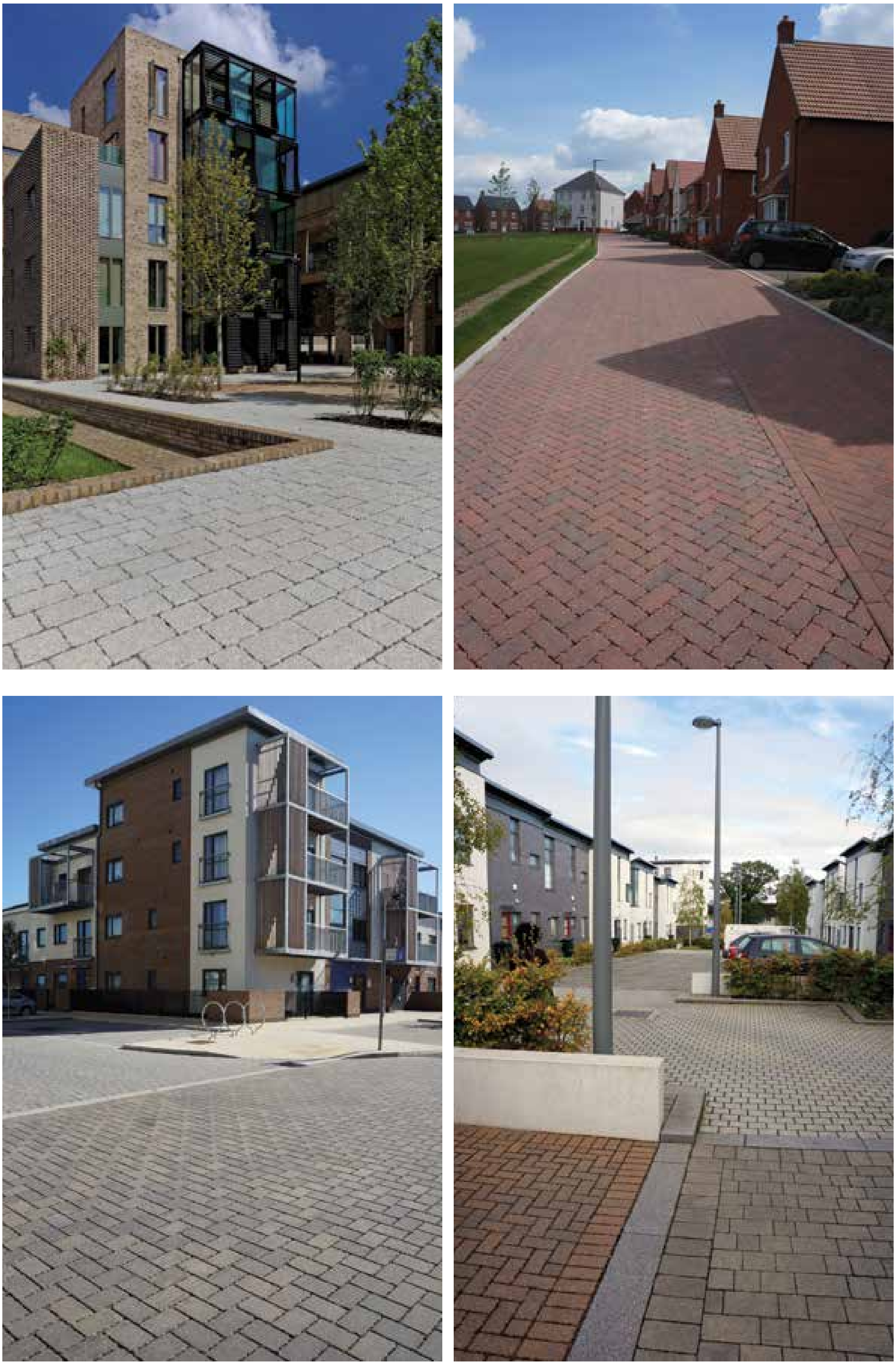

Figure 20.18 Examples of different block paving finishes (courtesy Interpave)

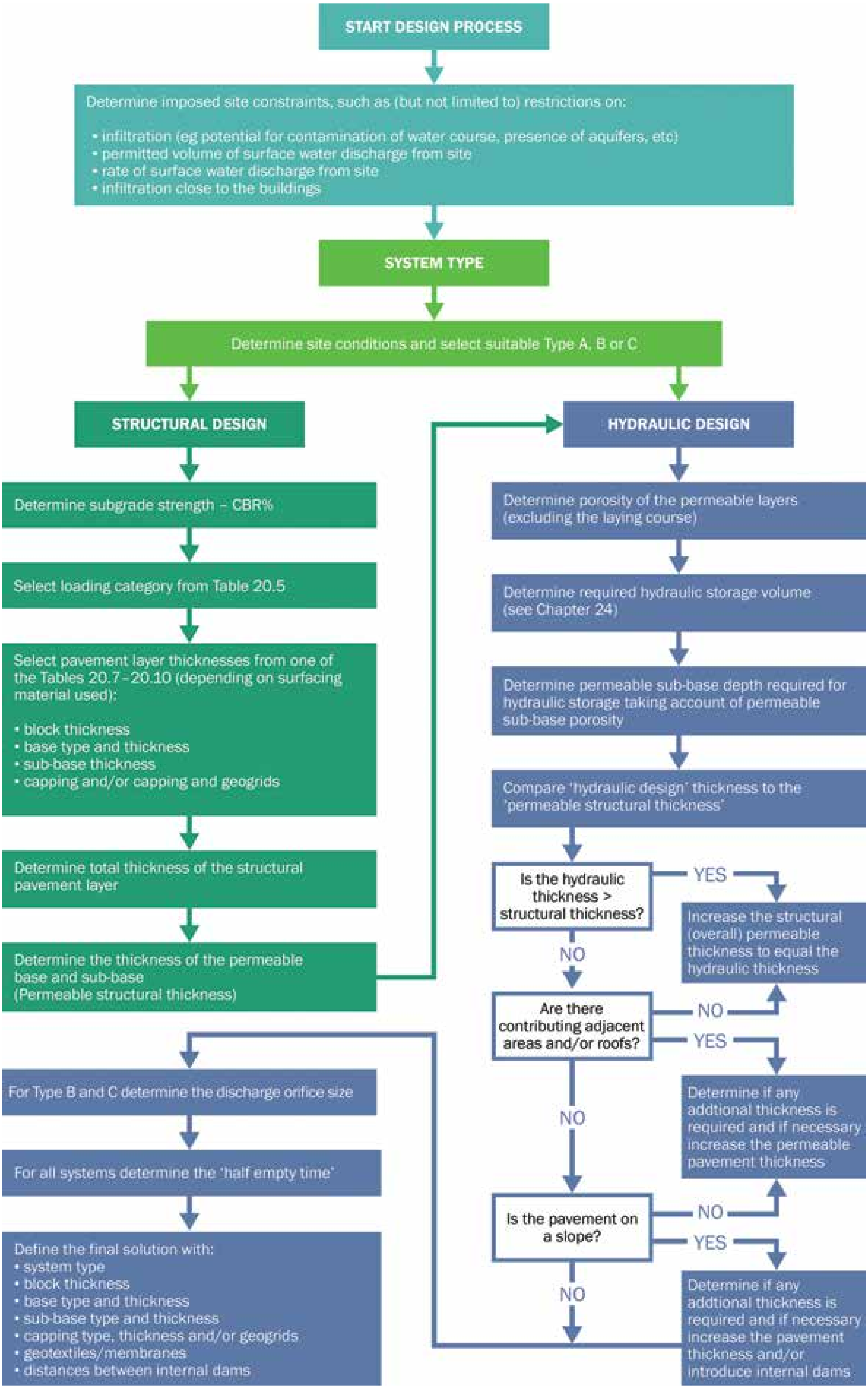

Figure 20.19 Pervious pavement design flow chart (after Interpave, 2010)

20.5 HYDRAULIC DESIGN

20.5.1 General

There are four aspects to the hydraulic design of pervious pavements:

a) confirmation of the adequacy of the rate of infiltration of rainwater through the pavement surface

b) calculation of the storage volume required for design storm event management

c) calculation of the outfall capacity required to convey and control the discharge of water from the pavement structure

d) exceedance design

Exceedance design is discussed in **Section 20.5.5**, while (a), (b) and (c) are discussed here.

a) Infiltration of rainwater through the pervious surface

The surface infiltration rate should be significantly greater than the design rainfall intensity to avoid surface water ponding, and the calculation of the inflow rate should include all anticipated runoff from adjacent areas. Typically, infiltration capacities of pervious surfaces are significantly greater than design rainfall intensities and are not generally limiting factors for the use of a pervious pavement. Surface ponding of exceedance events should be planned for in the design, taking account of the likely water depth on the surface and the time for which it is likely to remain. Note that the surface infiltration capacity has no relationship to the infiltration capacity of the soils below the pavement construction.

A minimum value of 2500 mm/h (for new pavements) is considered reasonable for a pavement surface to be considered pervious in respect of surface water management (when tested in accordance with standard test methods). The infiltration capacity of the surface materials is normally stated by the supplier or manufacturer. There is no standard UK or European test procedure for measuring the surface infiltration rate of pervious surfaces. However, ASTM C1781M-13 has been developed for concrete block permeable paving and ASTM C1701M-09 for pervious concrete (it could also be applied to other porous materials such as porous asphalt and gravel- or grass-filled reinforcement systems). It is recommended that manufacturers should provide surface infiltration rates measured using test methods and that they are adopted as a standard method in the UK with the following amendments:

1 The results should be stated in both mm/h and m/s.

2 Sealing the infiltration ring to the surface to be tested should be achieved using mastic sealant, rapid set mortar or other suitable sealant material.

There is no doubt that the rate of infiltration through porous and permeable surfaces reduces over time. The main ways that the surfaces become blocked are:

- washing of topsoil and construction materials onto the surface – these risks should be reduced through construction best practice and appropriate detailed design
- accumulation of silt and debris in the joints or pore spaces at or close to the surface
- the application of gritting sand to car park surfaces (not common practice in the UK) and the use of sand as a jointing material in concrete block permeable paving (not UK practice)
- binder slumping from the aggregate matrix in porous asphalt over time, which then drains into the voids – the risk of this occurring should be reduced by the use of modern binder technology to promote adhesion of the binder.

However, it is very rare that the clogging causes complete sealing of the whole surface, and normally it will continue to provide sufficient drainage capacity. It is recommended that a factor of safety of 10 is applied to the surface infiltration rate of all surface types, to allow for clogging to affect a proportion of the surface area over the pavement design life (ie the long-term surface infiltration rate will be a minimum of 250 mm/h). Information on rehabilitating pavements that suffer from clogging is provided in **Section 20.14**.

Despite the reduction in surface infiltration rate over time, the available evidence (**Table 20.2**) indicates that the long-term reduced rate is more than sufficient in most cases to deal with any rainfall intensities likely to occur in the UK. Even if the pavements become completely clogged, the evidence shows that they can be rehabilitated using sweepers combined with re-gritting of the joints.

Figure 20.20 shows an example of concrete block permeable paving after a 50 mm depth rainfall event. This pavement was about six years old at the time and had not been maintained in that time.

TABLE 20.2 Evidence of durability and clogging of the surfaces of pervious pavements

Pervious pavement type	Clogging mechanism	Evidence of likely clogging rates/extents	Rehabilitation mechanisms
Grass reinforcement (concrete grids)	Sand-filled voids with grass overgrowth act like sand filters and trap sediment close to the surface	Clogging depths of 6–12 mm (Urban Waterways, 2011); loss of 60–75% of the initial surface infiltration rate during a simulated 35-year life (Jayasuriya *et al*, 2007)	Clogged sand can be removed and replaced with mechanical sweepers, although the grass will also have to be reseeded
Porous asphalt	Dust and sediment trapped in surface pores	Clogging in the top 25–75 mm can occur rapidly without good design and maintenance, where silt loads are significant. Evidence in the UK is that pavements are still serviceable after about eight years	Rotating sweeper and jet wash; use a surface layer with finer pores (ie smaller aggregate) and increasing aggregate size with depth (Beeldens and Herrier, 2006)
Porous concrete	Dust and sediment trapped in surface pores	Clogging in the top 25–75 mm can occur rapidly without good design and maintenance, where silt loads are significant	Use a surface layer with finer pores (ie smaller aggregate) and increasing aggregate size with depth (Beeldens and Herrier, 2006); specialist rotating and oscillating sweeper (the type used to remove tyre residue from airport runways
Concrete block permeable paving	Dust and sediment is trapped in the joints between the blocks	Penetration to 50 mm (over six years) (Urban Waterways, 2011); loss of 70–90% of as-new surface infiltration rate over the first few years of use after which infiltration rate levels off and remain effectively constant (Borgwardt, 2006); in heavily trafficked pavements the wheel tracks may become completely clogged in a few years (Chaddock and Nunn, 2010)	Brushing and suction sweeping of the surface, replacement of top 20 mm of jointing material, herbicide application and weed removal programmes

b) Pavement subsurface storage capacity

The required capacity of the sub-base depends on rainfall characteristics, design return period, infiltration potential into the subgrade, discharge constraints, and the impermeable area draining to the pervious pavement.

The thickness of the sub-base required can be obtained by simple calculation (see Interpave, 2010) or by detailed hydrological and hydraulic modelling. It should be noted that the Interpave procedure assumes no time of concentration, which is likely to output a conservative design depth requirement. Proprietary drainage software now exists that can predict hydraulic profiles across a pavement and computes capacities for design events in more detail. However, many of the algorithms in the models are still very simple and only approximate to actual performance.

Analysis (Kellagher, 2013) shows that typically, at least twice the area of the pavement surface can be served by the sub-base when very tight throttle controls are applied, and nearly three times the area when the throttle rate is greater than 5 l/s/ha. However, where adjacent areas drain into the surface, the ratio of impermeable to pervious should be limited to 2:1 to prevent clogging. If roof water discharges into the sub-base via catch pits, the ratio can be increased.

Figure 20.20 Concrete block permeable paving after a 50 mm rainfall event (courtesy EPG Limited)

Where partial or total infiltration systems are used, the infiltration will mean that the system can therefore serve even greater areas. However, care should be taken not to hydraulically overload the pavement, as this can cause soil stability risks due to saturation.

Calculations for a range of rainfall durations should be carried out to verify the performance of the available storage volume.

The available storage in the base/sub-base layer is determined by the volume of the sub-base, the slope of the pavement and the usable voids (ie voids that are freely draining) within the aggregate. A commonly used value of porosity is 30% for the aggregates that meet the requirements for coarse-graded aggregates in BS 7533-13:2009 or Type 3 sub-base in accordance with DfT (1998). Care should be taken if using values higher than this, that all the voids in a material are free draining (eg clay soils may have a porosity but the voids are very small and not suitable for storing water). If a porosity greater than 30% is used in the design, the material should be tested on site to confirm compliance.

On sloping sites, the volume of available storage within the sub-base will be reduced when compared to a flat surface. ICPI (2011) suggests that where slopes are 3% or greater, designers should consider terracing or internal check dams in the sub-base to provide a series of compartments (BS 7533-13:2009) Where the water infiltrates to the soil below, this solution is easy to design, as the different compartments do not need to be interconnected with pipes.

For Type C systems, water still has to be allowed to flow out of the sub-base that is confined by the check dam into the lower compartment via a pipe or other structure. Flow can be from one compartment to another if it is possible to provide a sufficiently low flow control (very small orifices may be required). The minimum size of orifice should be 20 mm. Solutions to this issue include combining areas so that a larger flow control can be used, or discharging several dammed areas to a single larger flow control outside the permeable pavement area (if levels permit). The design of the flow control and interconnecting pipe should minimise the risk of blockage. Wherever possible, the design should allow access to either side of the flow control in case it needs to be unblocked (although the risk of this occurring is very low).

Other solutions to storage on sloping sites include terracing the site into a series of flat areas, making the formation as a series of horizontal terraces with the pavement surface sloping above them, making the sub-base thicker so that the water at the low end of the pavement remains within the sub-base or providing extra storage in a trench at the toe of a slope.

Research into the potential impact of surface slope on infiltration rates into the pavement surface has demonstrated that below slopes of approximately 20%, this should not be a significant issue. The impact of slope on storage and potential design solutions are shown in **Figure 20.21**.

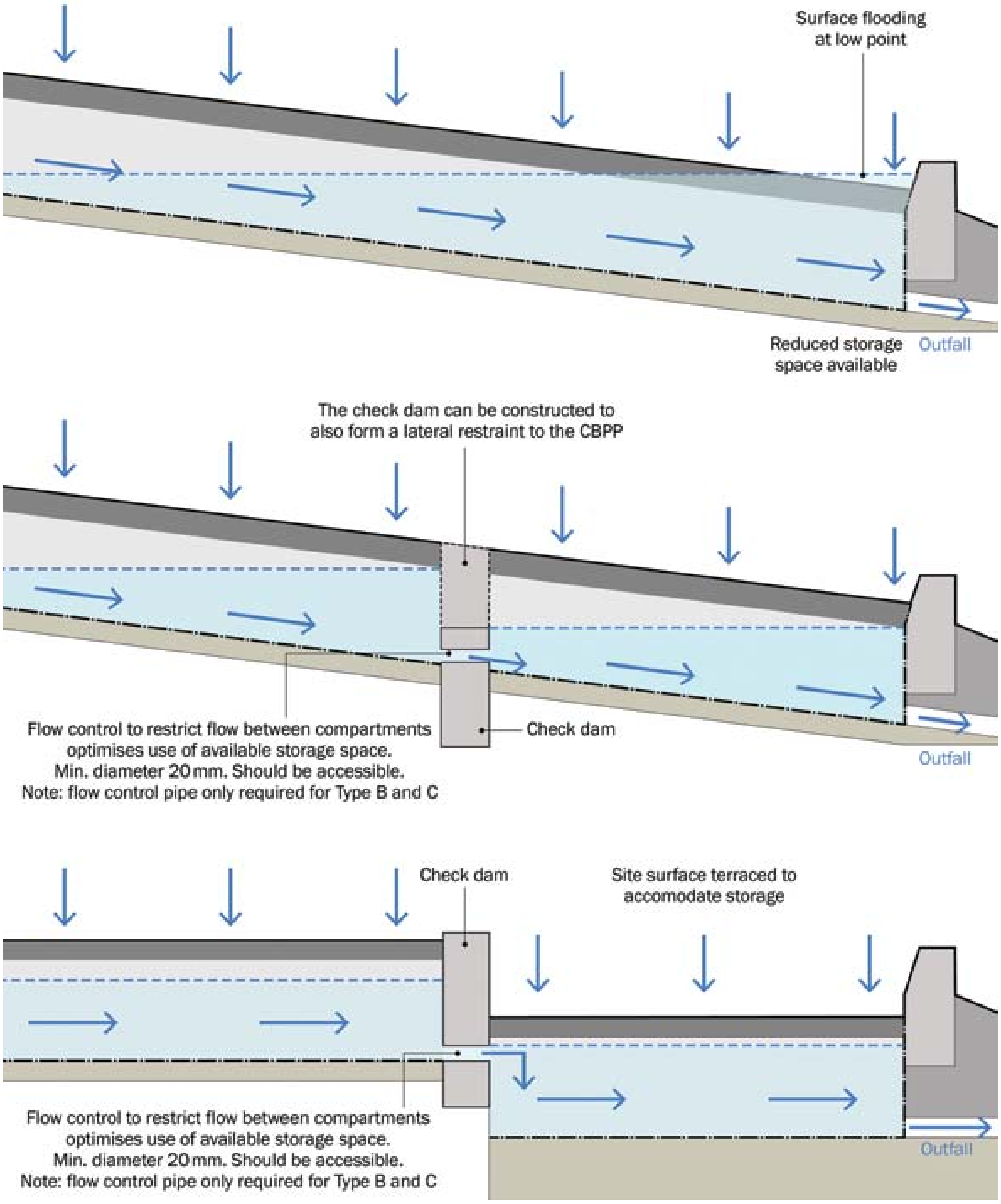

Figure 20.21 Control of water on sloping sites (from Interpave, 2013)

c) Outflow from the pavement structure

For the sub-base storage to operate effectively, the system requires flow controls (unless the only discharge mechanism is via infiltration). These are generally small orifice plates in a control chamber and can be very small (minimum 20 mm) because the risk of blockage is low, because the water has been filtered. Where the sub-base is divided into discrete areas (separated by impermeable construction), careful consideration is required of flow control locations and characteristics to ensure that the use of the storage is optimised and that there is no risk of inappropriate constriction and potential flooding. The outflow can also be to a rainwater harvesting system via a sump and pump chamber.

The spacing of the outlet pipes or collector pipes for sealed systems can be determined in an approximate manner using guidance provided by Cedergren (1974). The maximum surface runoff rate that can be removed by a flat permeable sub-base can be estimated using **Equation 20.1.**

EQ. 20.1 **Equation to estimate outfall pipe spacing**

$$q = k\,(h/b)^2$$

q = maximum intensity of rainfall entering into the pavement sub-base that can be drained by pipes at spacing of 2b and sub-base thickness of h (m/s)

k = coefficient of permeability of sub-base (m/s) (minimum value is specified in **Section 20.11**)

h = maximum depth of water stored in sub-base (and base if appropriate) above impermeable formation or membrane (m)

2b = distance between pipes (m)

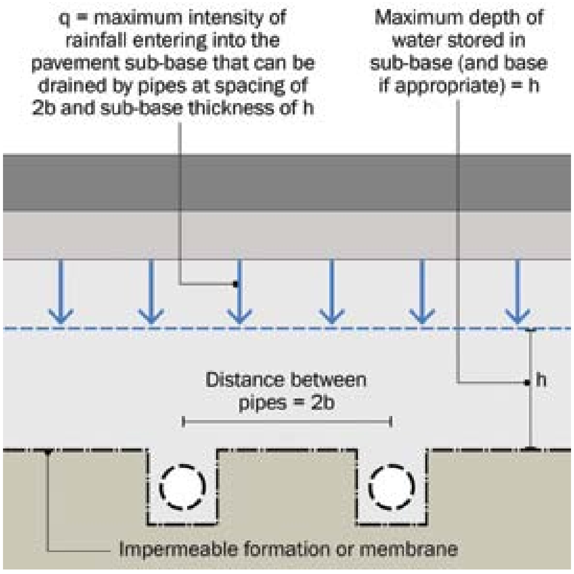

Figure 20.22 Outfall pipe spacing (after Interpave, 2010)

Water should flow horizontally through the sub-base to reach the outlet collection systems and there should be sufficient capacity in any aggregate to convey the rates of flow required. Horizontal water flows can very crudely be estimated using Darcy's law (ICPI, 2011) – **Equation 20.2.**

EQ. 20.2 **Darcy's law to calculate sub-base flow**

$$Q = A.k.i$$

Where

Q = flow capacity of sub-base (m^3/s)

A = cross-sectional flow area, ie height × width of sub-base through which water is flowing (m^2)

k = coefficient of permeability of sub-base (m/s) (minimum value is specified in **Section 20.11**.)

i = hydraulic gradient (m/m) (The hydraulic gradient is the head of water driving the flow. For this purpose, it is assumed to be the slope of the subgrade towards the outlet. This is not the true hydraulic head, but is a simple approximation which is generally conservative.)

Outflow from the sub-base should be via a system of perforated pipes or fin drains that provide a large surface area for water to flow into. Outlets that comprise simply the open end of a pipe (wrapped in geotextile) are prone to clogging and are not suitable. Perforated pipes should extend at least 1 m into the sub-base, and the pipes should be slotted or have circular holes formed as part of the manufacturing process. Perforations should not be made in pipes by site operatives. The perforated section of pipe should have sufficient flow capacity through the walls to manage the anticipated flows, and the perforations should be compatible with the aggregate size, such that migration of aggregate particles into the pipe is prevented. The capacity of the pipe to convey water should also be sufficient to manage anticipated flows. The open ends of any pipes that end in contact with gravel should be capped.

20.5.2 Interception design

Studies have shown that the frequency of runoff from all types of pervious pavements is significantly reduced when compared to gulley and pipe systems draining impermeable surfaces. Kellagher (2013) found that very high levels of compliance with Interception criteria are achievable through the use of pervious pavements, providing there is a nominal level of infiltration available. This is because, during small events, the water soaks into the pervious surface, laying course and sub-base, and is released back into the atmosphere through evaporation once the rainfall has stopped. In unlined systems (Type A and B pavements), infiltration can also deliver Interception. The results of various studies demonstrating the ability of pervious pavements to provide Interception storage are summarised in **Table 20.3**. These show that runoff typically does not occur from pervious pavements for rainfall events up to 5 mm.

TABLE 20.3 Interception storage provided by pervious pavements

Site	Reference	Type of pervious pavement	Interception storage (rainfall required to initiate runoff – mm)		
			Maximum	Minimum	Average
National Air Traffic Control Services, Edinburgh	Pratt *et al* (2001)	CBPP	17.2	2.6	7.3
Kinston, North Carolina	Collins *et al* (2008)	CBPP	> 5	n/a	n/a
Sydney, Australia	Rankin and Ball (2004)	CBPP	16	2.5	5[1]
North Carolina	Collins *et al* (2008)	Concrete grass grid	—	—	6
Toronto	Drake *et al* (2012)	CBPP and porous concrete	—	—	7

Note

1 Typical from curve fit of results

Permeable pavements can be combined with rainwater harvesting systems, which is another approach to providing Interception (**Chapter 11**).

20.5.3 Peak flow control design

Permeable pavements help reduce flow rates from a site by providing attenuation storage. The available storage volume is provided by the void space in the sub-base:

Available attenuation storage in sub-base =
Volume of sub-base × porosity in the soil/aggregate/ geocellular layer designed to be the storage volume

On sloping sites, the volume of storage will be reduced compared to the same area on a level site. The volume of storage in a sloping site is given by:

Available attenuation storage in sub-base =
0.5 × L × B × T × porosity in the soil/aggregate/geocellular layer designed to be the storage volume

Where

L = length of sub-base where water can be stored = T/tan β

T = thickness of sub-base measured vertically

B = width of sub-base where water can be stored

β = slope angle

A flow control structure is required to constrain the rate of water discharged from the sub-base via an outlet pipe. Where designs are accommodating small areas of pavement (eg for driveways and access routes), it may be appropriate to link adjacent pavements together so that the control system can be larger. The required storage volume for peak flow control should be assessed in accordance with **Section 24.9.**

20.5.4 Volume control design

Contribution of permeable pavement systems to volume control should be evaluated using standard methods, based on expected infiltration rates and/or available attenuation storage and specified flow controls. Assessment of volumetric control should follow the method described in **Chapter 3**.

To achieve suitable volumetric control, overflows to different areas of the drainage system may be required or alternatively the flow control at the outlet can be designed to provide a variable discharge. The use of rainwater harvesting (using the permeable pavement as the storage) can also be used to help to achieve a volumetric reduction in runoff.

20.5.5 Exceedance flow design

Pervious pavement systems should include exceedance event management as an integrated part of the system design. One option is to use gullies set slightly above the elevation of the pavement. This allows for some ponding above the pavement surface to be used for extra storage.

Temporary storage of runoff from extreme events above the pavement surface should not be permitted where there is a risk of surface clogging from deposited sediments and other debris.

▶ Further guidance on exceedance design is provided in **Section 24.12**.

20.6 TREATMENT DESIGN

Permeable pavement drainage has been shown to have decreased concentrations of a range of surface water pollutants when compared to impermeable surface drainage, including heavy metals, oil and grease, sediment and some nutrients (Pratt *et al*, 1995 and 1999, James and Shahin, 1998, Brattebo and Booth, 2003, Bean *et al*, 2007, Drake *et al*, 2012). All but nutrient removal has been repeatedly demonstrated in many research locations. Evidence of the removal efficiencies of permeable pavements are included in **Chapter 26, Annex 3**.

Because most permeable pavements substantially reduce the volume of runoff and outflow, it is logical that they will also significantly reduce pollutant loadings to receiving surface waters. The acceptability of allowing infiltration from the pavement will depend on the extent of the likely runoff contamination and site characteristics (see **Chapter 4, Table 4.3**).

Several studies confirm that permeable pavements demonstrate significantly lower total pollution loadings than standard pavements (Day *et al*, 1981, Rushton, 2001, Bean *et al*, 2007, Drake *et al*, 2012).

Treatment processes occurring within pervious pavements include:

- filtration of silt and the attached pollutants – the majority of silt is trapped within the top 30 mm of the jointing material between the blocks
- biodegradation of organic pollutants, such as petrol and diesel within the pavement construction
- adsorption of pollutants (pollutants attach or bind to surfaces within the construction) which depends on factors such as texture, aggregate structure and moisture content
- settlement and retention of solids.

Enhanced soils can also be used to improve treatment within the pervious pavement system. This can be achieved using either proprietary systems or by the addition of small amounts of substrate, or materials with a higher adsorption capacity than conventional aggregates (sawdust, peat, clay soils, granular activated carbon can all increase adsorption). The added materials should not reduce the structural or hydraulic performance of the aggregates. The required microbes are usually already present in the ground and further applications of microbes is not required.

The pollutants are trapped within the construction at various locations according to the type of pervious construction. It has also been found that oils held in some types of pervious construction may be degraded by microorganisms (Pratt, 1999). Hence oil saturation of the pavement is unlikely where supply is evenly spread over time. A major oil spill could overwhelm the system, but this risk can be mitigated by using specialist oil adsorbing geotextiles within the construction (a heavier weight geotextile will be more effective, especially if it has been specifically developed to attract oil). It is thought likely that nutrients occurring in the environment near pervious pavements, such as in grass cuttings, leaves and animal droppings, may well provide the required stimulus for indigenous microbial community development. For sites with a low risk of oil spillage, there is no need to use geotextile between the bedding layer and sub-base for pollution removal performance, because the geotextile makes little if any difference to removal of other pollutants.

If geocellular storage is used instead of aggregate sub-base, the benefits of treatment within the sub-base gravels will be lost. However, the use of a horizontal geotextile above the geocellular units can help mitigate this loss (Puehmeier and Newman, 2008), and has been demonstrated to provide comparable performance. Also, a significant proportion of the pollution removal has been demonstrated to occur in the top of the jointing voids in concrete block permeable paving, the top layer of porous asphalt (if the surface layer has a smaller grading) and in the grass/rootzone layer of grass systems.

If increased confidence in the removal of nitrogen has to be achieved then water would have to be fed from the sub-base material below the pervious pavements to the next stage of the Management Train, specifically designed to optimise nutrient removal. This could be achieved by linking up the pavements to a pond or series of ponds or bioretention system with an anaerobic zone as these have better removal rates for phosphorous and nitrogen. Concrete grass grid pavers filled with sand have been found to be more effective at removing total nitrogen than other types of pervious surface (Urban Waterways, 2008).

Drake *et al* (2012) found clear differences in water quality issuing from CBPP and porous concrete. The two surfaces appear to capture different pollutants. This may be the result of the higher pH conditions within the porous concrete affecting metal adsorption. There was also initial leaching of some contaminants from the concrete (phosphate and high pH). Porous concrete also takes time to stabilise and, in the longer term (1 year +), performance seems to approach that of CBPP.

The treatment design should ensure that the surface layer has sufficiently small voids to trap silt within 30 mm of the surface but still be permeable enough to allow water to flow into the sub-base. Porous asphalt, porous concrete, reinforced grass, resin bound gravel and concrete block permeable paving with 2/6.3 jointing material should all meet this requirement.

20.7 AMENITY DESIGN

Pervious pavements can provide amenity in the form of both the usefulness (ie they afford flexible and multiple use of space for a wide range of activities) and the visual aspects of the surface materials (especially grass systems). However, there are no specific design requirements to achieve amenity over and above the choice of surface as part of the overall planning, architectural or landscape design.

20.8 BIODIVERSITY DESIGN

Pervious pavements do not provide any direct biodiversity benefits, although they are very useful for treating and controlling water to maximise the biodiversity in any downstream ponds or wetlands. There are no specific design requirements or approaches for biodiversity.

20.9 STRUCTURAL DESIGN (PAVEMENT ENGINEERING)

20.9.1 Introduction to structural pavement design

The pavement design philosophy introduced by Powell *et al* (1984) is still the basis for flexible pavement design in the UK. The soil below a road pavement is usually much weaker than the road pavement materials and cannot support direct wheel loads. The main principle of road pavement design is that the constructed layers distribute the concentrated loads from wheels to a level that the soil below the road (referred to as the subgrade) can support without failure or excessive deformation. At the surface of the road, the pressure from wheels is the highest, and so strong, high quality materials are used in the upper layers (eg concrete, asphalt, block paving). The pressure reduces with depth allowing weaker materials to be used lower in the pavement (as sub-base and capping layers). In the longer term, the capping and/or sub-base prevent groundwater reaching the bound upper layers.

The main layers that are placed to form a road pavement are shown in **Figure 20.23**.

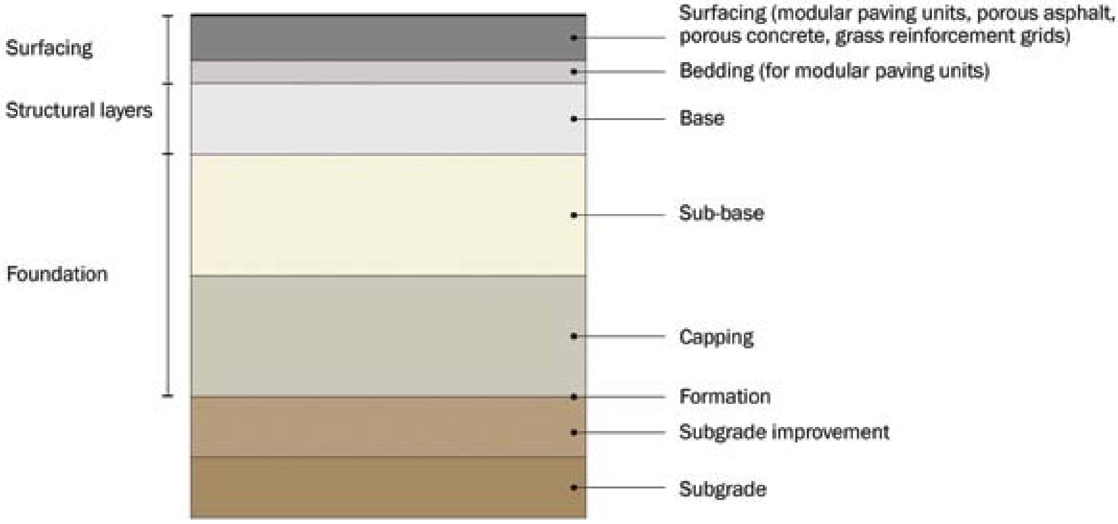

Figure 20.23 Layers in a road pavement construction

The capping and sub-base layer are known as the foundation and should give sufficient load-spreading to provide an adequate construction platform and base for the overlying pavement layers. The asphalt, asphalt concrete, concrete, blocks or other pavement materials are referred to as structural or surface layers and should not crack or suffer excessive rutting under the influence of traffic. One of the main structural layers is the base, which will usually comprise either porous asphalt, asphalt concrete or hydraulically bound material. The base layer is of particular importance in concrete block paving designed to carry regular HGV traffic.

20.9.2 Pervious pavement structural design principles

Although no approved structural design methods for pervious pavements exist in the UK, there are a number of general principles that should be followed when pervious pavements are designed. Guidance by Pratt *et al* (2001) should be referenced for supporting detail on pervious pavement design methods and materials.

Normal road pavement materials are not intended to allow water into the construction. Pervious pavements do allow water into the construction, and this means that the pavement should be designed and the materials specified, so that it can support traffic when saturated while allowing water to flow freely through it. The materials used for pervious pavement construction should be graded to give the right balance between achieving good structural performance and providing sufficient permeability and void space for water storage. Care should be taken to ensure that loss of finer particles between unbound layers does not occur, as this can reduce the strength of granular layers. Geotextile can be laid between unbound layers to prevent this from occurring. Where a geotextile is not provided between laying course and sub-base, the aggregates should meet standard geotechnical filter criteria (**Section 30.5.3**).

The other overriding consideration is that the surfacing will be sufficiently durable and can withstand the likely turning and impact forces from traffic with damage (eg spreading of blocks under excessive traffic shear forces).

In general, the approach taken to all surfaces is as follows, following Knapton *et al* (2012):

1 For lightly trafficked pavements, the loads applied by wheels are the critical factor, and the guidance for those pavements is based upon wheel loads.

2 For more heavily trafficked highway pavements, the pavements are designed on the basis of the cumulative number of standard 8000 kg axles.

20.9.3 Determination of the CBR value for design of pervious pavements

Design CBR value

Californian bearing ratio (CBR) varies inversely with moisture content (as the latter increases the CBR value decreases). The equilibrium CBR value is the long-term value that occurs once the pavement is constructed and the moisture content of the subgrade soil comes into equilibrium with the suction forces within subgrade pore air spaces. Suction forces can occur as a result of unloading due to excavation. Changes in groundwater levels or wetting as a result of water storage in the sub-base will also affect the equilibrium CBR value. Equilibrium CBR values should be used for permeable pavement design. This can be determined by carrying out laboratory CBR tests in accordance with BS 1377-4:1990 at the equilibrium moisture content as described by Powell *et al* (1984). For Type A and B pavements the CBR should be tested after saturation. The ICPI (2011) recommends a 96-hour saturation period.

Alternatively, the value should be estimated based on the type of soil (plasticity index and grading) following the guidance by Powell *et al* (1984) and BS 7533-13:2009, as provided in **Table 20.4**.

TABLE 20.4 Equilibrium subgrade CBR estimation

Soil type	Plasticity index	Guideline equilibrium CBR Value for pervious surface design[1, 3] (%)
Heavy clay	70	2
	60	2
	50	2
	40	2.5
Silty clay	30	3
Sandy clay	20	4
	10	3
Silt[2]	–	1
Sand (poorly graded)	–	7
Sand (well graded)	–	10
Sandy gravel (well graded)	–	15

Note

1 Assumes thin construction. If pavement thickness (from surface to subgrade) is greater than 1200 mm (see HA, 2009).

2 Estimated assuming some probability of material saturating.

3 These CBR values assume a high water table and that the subgrade may be wetted during the life of the pavement.

The highest values of plasticity index measured on a site should be used (to give the lowest CBR value) for the design, unless there are a substantial number of results available to allow the mean or other statistical value to be used with confidence, but if the mean is used, there will be an increased risk of pavement failure in some areas. It may be possible to remove soft spots and therefore ignore those low CBR values which relate to the removed material.

On sites where the CBR varies from place to place, appropriate designs may be provided for different parts of the site using the lowest CBR recorded in each part.

Once the subgrade is exposed during construction, the CBR value of the soil should be confirmed by laboratory testing of CBR samples (BS 1377-4:1990) or using *in situ* methods (BS 1377-9:1990). This is the short-term CBR value at the time of construction. If it is found to be less than the design CBR, the subgrade should either be improved to achieve the design CBR, or the foundation thickness should be redesigned. The reason for this is because construction during very wet weather can adversely affect the soil strength and lead to lower equilibrium CBR values.

In summary the final design CBR value should be the lower of:

1 the equilibrium CBR value obtained from CBR tests at equilibrium moisture content (saturated for 96 hours for Type A and B) or based on plasticity and grading results using the correlations above

2 the short term CBR value obtained from CBR tests on the subgrade, taken once it is exposed for construction.

Subgrade with low CBR (CBR < 2.5%)

British Standard BS 7533-101:2015 specifies that the minimum permitted design CBR is 2.5% for normal pavements and this also applies to pervious pavements. Subgrades with a lower design CBR are considered unsuitable to support a pavement foundation. In these cases, a subgrade improvement layer should be provided to permanently improve the load-bearing capacity of the subgrade. This can be achieved by removing the weak material to sufficient depth and replacing it with suitable fill material. The thickness removed may typically be 0.5–1.0 m. Although the new material may be of better quality, the new design CBR should be assumed to be equivalent to 2.5%, in order to allow for effects of any softer underlying material and the potential reduction in the strength of the replacement material to its long-term CBR value.

The existing subgrade materials may also be improved by the addition of lime and/or cement to give an acceptable long-term CBR value if the areas with a low CBR are extensive. This will only be possible with Type C pavements (no infiltration). The impact of water on the stabilised materials should be carefully considered.

The incorporation of a geosynthetic material into the foundation design may also overcome the issue of a weak subgrade. Specialist advice should be sought to adopt an alternative design CBR value that may be necessary, based on testing or previous experience with the specific geosynthetic and the materials being used on the scheme.

20.9.4 Traffic categories

Pervious pavements can be designed to carry any volume of traffic loads. **Table 20.5** defines traffic loads in terms of traffic categories. These traffic categories can be used for the design of any type of surfacing including porous asphalt and other materials and are used as the basis for the structural design of all types of surface discussed in this manual.

TABLE 20.5 Traffic loading categories for pervious pavement design

Traffic category (BS 7533)	Standard axles per day	Lifetime traffic (msa)	NRSWA road type	Maximum anticipated axle load (kg)	Example number of commercial vehicles per day[1]	Typical application
11	Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations 1986 as amended are not included in this document					
10	≤ 4,000	≤ 60	0	Site specific (see Knapton, 2007)		Adopted highways and commercial/industrial developments used by a high number of commercial vehicles Ports and airport landside Bus stops and bus lanes
9	≤ 2,000	≤ 30	1	Site specific (see Knapton, 2007)		
8	≤ 700	< 10	2	8000	Approx 420	
7	≤ 275	< 2.5	3	8000	Approx 170	
6	≤ 60	< 0.5	4	8000	Approx 35	Adopted highways and other roads used by a moderate number of commercial vehicles Pedestrian areas subjected to regular overrun of commercial vehicles Industrial premises Petrol station forecourts
5	≤ 5	< 0.05	n/a	8000	Approx 3	Pedestrian areas subjected to occasional overrun of commercial vehicles and maintenance/cleaning machines Car parks receiving occasional commercial vehicular traffic Railway platforms excluding edge
4	1	n/a	n/a	8000	Mainly car or pedestrian traffic with emergency HGV vehicles only	Urban footways with no planned vehicular overrun Pedestrian areas or car parks used by light commercial vehicles emergency vehicles and by maintenance vehicles
3	0	n/a	n/a	2,000	No HGV	Small car parks subject to car, light van and motorcycle access
2	0	n/a	n/a	1,000	No HGV	Pedestrian and cycle areas, domestic driveways
1	0	n/a	n/a	1,000	No HGV	Pedestrian-only areas, including domestic applications
0	0	n/a	n/a	0	No vehicular traffic	No requirement (decoration)

Note

1 Based on 1.7 standard axles per vehicle.

No commercial vehicle traffic loading

Site categories 0, 1, 2 and 3 should only be selected where it can be ensured that no commercial vehicles use the pavement, for example where bollards or height barriers have been installed.

In determining the site category, the use of the surface of the pavement by any construction traffic should be assessed and allowed for.

Pedestrian loading and maintenance vehicles

Open areas are now being increasingly maintained by mechanical sweepers and other collection vehicles that can have surprisingly high wheel loadings and other detrimental effects (eg suction sweepers) on paved areas. Their use should be assessed in determining the traffic category appropriate to adopt for the design.

Amenity areas

In areas where there is no possibility of vehicular access (eg patios and private garden paths), a category 0 or 1 design may be adopted

Site traffic

Where the site is to be used for construction traffic, the layer to be used by that traffic should be of adequate strength for the use. Normally the completed base should be adequate, but in case of doubt (eg for a large-scale development), an estimate of the traffic should be made and a pavement design carried out using current design guidance for bound or unbound pavements.

In areas not subject to commercial vehicle traffic, the design should consider loading during construction and maintenance of adjacent areas, and other vehicles that might access the area, including emergency vehicles. Their use should be allowed for in the design.

Design life

A 20-year design life should be generally applicable (structural) unless access for possible maintenance of the base is likely to be difficult or expensive, in which case a longer design life may be advisable. Where the pavement serves a finite area, zero growth in traffic is likely to be applicable. If calculated growth figures are available, these should be used to ascertain the number of standard axles.

20.9.5 Structural design approaches

The philosophy for conventional (ie non-pervious) pavement design is that the sub-base and/or capping layer is only influenced by the strength of the subgrade, with the thickness of the upper structural layers (base and surface courses) influenced by traffic loadings. The design method used in BS 7533-13:2009 for concrete block permeable paving is different, in that the traffic load does have an influence on the thickness of the sub-base and/or capping layer. Knapton *et al* (2012) have combined the two approaches for pervious pavements and used maximum wheel load design for lightly trafficked areas of pervious paving and a conventional axle fatigue approach for more heavily trafficked pavements. They also extended the scope for pervious pavements to heavy duty industrial pavements by applying the design approach proposed by Interpave (Knapton, 2007).

In the UK, the established design methodologies for flexible pavements with either an asphalt or hydraulic bound base can also be used to design porous asphalt pavements for heavily trafficked roads (Chaddock and Nunn, 2010). Structural design of pavements is most important for those surfaces used in areas subject to heavier or more frequent HGV traffic.

Analytical design is becoming more widely accepted in pavement engineering and can be applied to pervious pavements. Analytical design is a very useful approach, which allows the use of different porous or permeable materials, and it should be encouraged. However, it is vital that the material properties assumed in the design are achieved during construction (eg the stiffness of concrete block permeable paving should reflect normal construction practice and not rely on very high quality workmanship) and an appropriate site testing regime will be required. Also, the materials used in construction should provide all the other necessary attributes (eg durability and providing suitable skid resistance). Most analysis uses a simplified multi-layer linear elastic model, although finite element analysis can also be used (Knapton *et al*, 2012). An element of judgement will still be required in the design, based on experience of the performance of different materials. This approach can be used for a wide range of traffic conditions. In the USA, the ICPI (2011) has published a design program for concrete block permeable paving called Permeable Design Pro. Although this is based on USA design methods, there is no reason why it cannot be applied to UK design of concrete block permeable paving. One of the key design parameters in analytical approaches is the stiffness of the various materials, and values are provided in **Table 20.6**.

TABLE 20.6 Stiffness of various materials used in pervious surface construction

Material	Stiffness	Source
Porous asphalt	2 GPa	Chaddock and Nunn (2010)
	3.2–7.1 GPa	Chopra *et al* (2011)
Porous concrete	Range 25–45 GPa Typical 38 GPa	Dynamic modulus, Chaddock and Nunn (2010)
Permeable sub-base for use below all types of surfacing	93–138 MPa 250–400 MPa (but these would need reducing to allow for saturation by 40–70%, which in worst case would give 100–160 MPa)	ICPI (2011) Shackel (2006)
Concrete block permeable pavers	1000–4500 MPa depending on type of block	Shackel *et al* (2000)

Resilient modulus is a measure of stiffness under loads that are applied quickly (such as traffic loads). Shackel *et al* (2000) found that there was little difference in resilient modulus between permeable and non-permeable versions of block paving and also between different laying patterns. Paver shape was found to have a significant impact of resilient modulus.

Note that when measuring the stiffness of permeable sub-base materials on site, they are likely to return lower values than when unconfined on the surface. Experience, analysis (Interpave, 2007) and also testing (Chaddock and Nunn, 2010) have shown that once confined by the overlying pavement construction the stiffness will increase.

20.9.6 Structural design considerations for different surface types

The following sections provide specific information on structural design for various surfacing materials.

Grass reinforcement and resin bound materials

This section covers reinforcement grid systems that are plastic or concrete and infilled with grass or gravel. It also covers resin bound materials. There is no recognised UK design standard for these types of pervious pavements. Often designers rely on recommendations made by manufacturers. However, the surfacing provides very little contribution to the load-bearing capacity of the pavement structure and therefore the sub-base thicknesses used for asphalt or CBPP can be applied to these types of surface (ICPI, 2011).

The systems are often used with normal Type 1 sub-base below (ie not for water storage), in which case standard pavement design approaches should be used. If coarse-graded aggregate is used below the surfaces to store water, the sub-base depths in **Table 20.7** can be used. A capping layer or increased thickness of coarse-graded aggregate may be required where the CBR values are less than 5%. Where used with coarse-graded aggregate sub-base, a geotextile will be required between the sand bedding/growing layer and the sub-base, otherwise the sand will be washed down into the sub-base. These surface types are not recommended for load classes above site category 4.

TABLE 20.7 Typical construction thickness for grass reinforcement and resin bound materials over subgrade of 5% CBR or greater

Traffic category (BS 7533)	Grid	Bedding layer	Sub-base CGA
4	Varies	50 mm	300 mm
3	Varies	50 mm	225 mm
2	Varies	50 mm	150 mm
1	Varies	50 mm	100 mm
0	Varies	50 mm	Sufficient to provide suitable construction base

The sections in **Table 20.7** apply in the case of subgrades of 5% CBR or greater. For pavements over lower CBR values that are trafficked by vehicles, the following should be provided:

- 1% CBR subgrade improvement required (**Section 20.9.3**)
- 2% CBR subgrade improvement layer required (may be incorporated into capping layer to provide a total layer thickness of 350 mm)
- 2.5% CBR 300 mm capping
- 3% CBR 225 mm capping
- 4% CBR 150 mm capping

The capping layer design can also incorporate geogrid(s), which may reduce the required thickness of material. However, the sub-base and capping layer thickness may need increasing to allow for use by construction vehicles.

When used over open-graded sub-base such as Type 3, a geotextile separation layer will be required to prevent the sand infill/bedding layer from being washed into the underlying sub-base. Trials by Chaddock and Jones (2007) have shown that great care is needed in lapping the geotextile to ensure that washout does not occur. It is recommended that an overlap of at least 500 mm is provided, and that care is taken at the edges to ensure that localised washout cannot occur (lap the geotextile upwards at the edges and suitable folds at corners to contain the bedding sand).

Porous asphalt

Porous asphalt can be designed using analytical pavement design procedures using appropriate values of resilient modulus for the materials specified in the pavement. Alternatively, the advice in Chaddock and Nunn (2010) may be used to design the porous asphalt layers. Another approach is to combine the sub-base and other layer thicknesses specified by Knapton *et al* (2012) but replace the concrete blocks and bedding layers with a porous asphalt layer. This latter approach is the basis for **Table 20.8**. Further advice on the use of porous asphalt in car parks and private drives is provided by MPA (2009). Detailed guidance on suitable mixtures should always be obtained from the supplier.

The sections in **Table 20.8** apply in the case of subgrades of 5% CBR or greater. For pavements over lower CBR values that are trafficked by vehicles, the following should be provided:

- 1% CBR subgrade improvement required (**Section 20.9.3**)
- 2% CBR subgrade improvement layer required (may be incorporated into capping layer to provide a total layer thickness of 350 mm)
- 2.5% CBR 300 mm capping
- 3% CBR 225 mm capping
- 4% CBR 150 mm capping

TABLE 20.8 Typical construction thickness for porous asphalt over subgrade with 5% CBR or greater

Traffic category (BS 7533)	Porous asphalt	Base HBCGA[1]	Sub-base CGA[2]
11	Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations 1986 as amended are not included in this document[3]		
10	Asphalt requires specialist consideration and specification	Site specific using Interpave guide for heavy duty pavements (Knapton, 2007)	150 mm
9	Asphalt requires specialist consideration and specification	Site specific using Interpave guide for heavy duty pavements (Knapton, 2007)	150 mm
8	Design following Chaddock and Nunn (2010)[4]	300 mm HBCGA	150 mm
7	Design following Chaddock and Nunn (2010)	200 mm HBCGA	150 mm
6	180 mm 80 mm	– 125 mm HBCGA	150 mm 150 mm
5	160 mm 80 mm	– 100 mm HBCGA	150 mm 150 mm
4	150 mm	–	300 mm
3	120 mm	–	225 mm
2	70 mm (assumes hand lay)	–	150 mm
1	70 mm (assumes hand lay)	–	100 mm
0	70 mm (assumes hand lay)		Sufficient to provide suitable construction base

Note

1 HBCGA refers to hydraulically bound coarse-graded aggregate (conforming to BS EN 14227-1:2013), minimum cement content 3%, strength class C5/6 as defined in BS EN 14227-1 and minimum permeability 10,000 mm/hr when tested in accordance with ASTM C1701M-09 or other suitable test).

2 The sub-base CGA depths are minimum values that correspond with the equivalent thicknesses provided in Table 20.10 for modular surfacing. The sub-base CGA and any capping layer can also be designed to Foundation Class 2 in accordance with HA (2009).

3 Special vehicles (SV) fall outside the Road Vehicles (Construction and Use) Regulations 1986. SV vehicles comply with the Road Vehicles (Authorisation of Special Types) (General) Order 2003 or the Individual Vehicle Special Orders. They have higher axle loads and weights and are commonly known as abnormal loads.

4 The Chaddock and Nunn (2010) report was based on a pilot study. The tables in the report showing pavement designs for up to 80 msa (million standard axels) are an extrapolation of test data and have not been validated in full size schemes. If designs are required for traffic category 7 and above, specialist advice should be obtained from suppliers about whether porous asphalt is suitable and to provide an appropriate specification.

The capping layer design can also incorporate geogrid(s), which may reduce the required thickness of material. However, the sub-base and capping layer thickness may need increasing to allow for use by construction vehicles.

Note that porous asphalt may not be suitable as a surfacing in some locations (eg petrol forecourts, ports or bus stops) due to either the risk of degradation resulting from fuel spills or the nature of the risk of surface deformation resulting from the possible range of traffic forces.

Porous concrete

Porous concrete is not widely used at present in the UK. However, it is used in the USA, where comprehensive design and construction guidance is available (eg ACPA, 2011, CRMCA, 2009, ACI, 2010). A structural design programme for pervious concrete pavement design is available from the ACPA (called PerviousPave) and this can be adapted to design porous concrete paving for UK conditions. The equations used in the programme and the background information is provided by the ACPA (2011). Obla (2007) indicates that numerous applications have used a 125–150 mm thick pervious concrete layer over 150 mm sub-base. Field performance of these projects has shown that they are adequate to handle the traffic loads expected in car parks with mainly passenger cars with very occasional HGVs (trash trucks). Where heavier loads and higher traffic are expected, then US experience suggests using a thicker layer of porous concrete (200–300 mm).

Porous concrete is a near-zero-slump, open-graded material consisting of portland cement, coarse aggregate, admixtures and water. It has little or no fine aggregate (ACI, 2010). The combination of these ingredients will produce a hardened material with connected pores, 2–8 mm in size, which should allow water to pass through easily. The porosity can be 15–35%, with typical compressive strengths of (2.8–28 MPa). Porous concrete is laid as a plain concrete slab without reinforcement.

Recommended concrete and sub-base CGA thicknesses are provided in **Table 20.9**.

TABLE 20.9 Typical construction thickness for porous concrete over subgrade with 5% CBR or greater

Traffic category (BS 7533)	Porous concrete (plain slab)	Sub-base CGA
11	Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations 1986 as amended are not included in this document	
10	Site specific design	
9	Site specific design	
8	Site specific design	
7	Site specific design	
6	Site specific design	
5	150 mm	300 mm
4	135 mm	300 mm
3	125 mm	225 mm
2	125 mm	150 mm
1	100 mm	100 mm
0	100 mm	Sufficient to provide suitable construction base

The sections in **Table 20.9** apply in the case of subgrades of 5% CBR or greater. For pavements over lower CBR values that are trafficked by vehicles, the following should be provided:

- 1% CBR subgrade improvement required (**Section 20.9.3**)
- 2% CBR subgrade improvement layer required (may be incorporated into capping layer to provide a total layer thickness of 350 mm)
- 2.5% CBR 300 mm capping
- 3% CBR 225 mm capping
- 4% CBR 150 mm capping

The capping layer design can also incorporate geogrid(s), which may reduce the required thickness of material. However, the sub-base and capping layer thickness may need increasing to allow for use by construction vehicles.

The designs in **Table 20.10** have been assessed using ACPA (2011) assuming a 40-year design life, 0% growth, resilient modulus of sub-base CGA is 110 MPa and 28-day flexural strength of porous concrete is 2.8 MPa. For CBR less than 5% use the factors above to increase capping layer thickness or design using ACPA (2011).

Because there is currently no track record of using porous concrete in the UK, it is recommended that expert advice is obtained to undertake site specific designs for site categories 6–10.

Modular surfacing (including concrete block permeable paving)

This can be used for a wide range of traffic conditions from light to very heavy duty pavements. BS 7533-13:2009 provides standard thicknesses for the pavement layers, although these can be adjusted if materials with a different stiffness are used following the approach described by Knapton *et al* (2012) or using the ICPI (2011) design approach.

The structural design of CBPP suggested in **Table 20.10** has been developed from the approach of Knapton *et al* (2012). Their approach is based on a combination of finite element analysis of static wheel loads and analysis of full-scale test results. The main difference between **Table 20.12** and the Knapton *et al* (2012) approach is that the table provides the same construction thickness for all of Types A, B and C pavements. This is because any effect of infiltrating water should have been taken account of when choosing the design CBR value. In general, Types A and B pavements will result in lower design CBR values because of the presence of water in contact with the subgrade. The waterproofing layer and sand protection layer (or geotextile protection) provided in Type C systems do not have any influence on the structural design and therefore are not included in the table for structural design.

The design layer thickness has been checked using the guidance provided by the ICPI (2011). This approach makes assumptions about the default properties of the materials used in each layer, which are summarised in **Table 20.11**.

TABLE 20.10 Typical construction thickness for modular paving over subgrade with 5% CBR or greater

Traffic category	Type of surface – minimum thickness				Bedding layer nominal thickness	Base HBCGA[1] (porous) or AC (cored)	Sub-base CGA[2]	Design basis
	Concrete/ clay blocks	Natural stone slab	Concrete flag	Setts				
11	Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations 1986 as amended are not included in this document[3]							
10					Site specific using Interpave guide for heavy duty pavements (Knapton, 2007)			Knapton (2007)
9					Site specific using Interpave guide for heavy duty pavements (Knapton, 2007)			Knapton (2007)
8	80 mm				50 mm	300 mm HBCGA or 220 mm AC32	150 mm	
7	80 mm				50 mm	200 mm HBCGA or 130 mm AC32	150 mm	ICPI (2011)
6	80 mm				50 mm	125 mm HBCGA or 90 mm AC32	150 mm	
5	80 mm	Seek advice from supplier			50 mm	100 mm HBCGA or 70 mm AC32	150 mm	
4	80 mm				50 mm	–	300 mm	Knapton *et al* (2012) and ICPI (2011)
3	60 mm				50 mm	–	225 mm	
2	60 mm				50 mm	–	150 mm	
1	60 mm				50 mm	–	100 mm	
0	60 mm				50 mm		Sufficient to provide suitable construction base	

Note

1 HBCGA refers to hydraulically bound coarse-graded aggregate (conforming to BS EN 14227-1:2013), minimum cement content 3%, strength class C5/6 as defined in BS EN 14227 and minimum permeability 10,000 mm/hr when tested in accordance with ASTM C1701M-09 or other suitable test).

2 The sub-base CGA depths are minimum values that correspond with the thickness given by Knapton *et al* (2012) or from calculations using ICPI (2011). The sub-base CGA and any capping layer can also be designed to Foundation Class 2 in accordance with HA (2009).

3 Special vehicles (SV) fall outside the Road Vehicles (Construction and Use) Regulations 1986. SV vehicles comply with the Road Vehicles (Authorisation of Special Types) (General) Order 2003 or the Individual Vehicle Special Orders. They have higher axle loads and weights and are commonly known as abnormal loads.

The sections in **Table 20.10** apply in the case of subgrades of 5% CBR or greater. For pavements over lower CBR values that are trafficked by vehicles, the following should be provided (from Knapton *et al*, 2012):

- 1% CBR subgrade improvement required (**Section 20.9.3**)
- 2% CBR subgrade improvement layer required (may be incorporated into capping layer to provide a total layer thickness of 350 mm)
- 2.5% CBR 300 mm capping

- 3% CBR 225 mm capping
- 4% CBR 150 mm capping

The capping layer design can also incorporate geogrid(s) which may reduce the required thickness of material. However, the sub-base and capping layer thickness may need increasing to allow for use by construction vehicles.

AC refers to asphalt concrete (AC 32 dense 40/60 designed in accordance with BS EN 13108-1:2006.

For load class 5 and above, concrete block permeable paving should only be laid in a herringbone pattern.

Note for infiltration Type A systems the capping layer material should be sufficiently permeable to allow water to percolate through it, without it losing strength. It should also have an infiltration rate that is greater than the material below it. It should also be sufficiently durable and wear-resistant. Alternatively, an increased thickness of coarse-graded aggregate can be used. The grading for 6F2 capping (DfT, 1998) can be modified to reduce the amount of fines and make it more permeable (ie less than 5% passing the 63 microns sieve and 0–25% by mass passing the 600 microns sieve). This has been used successfully below infiltrating pavements.

TABLE 20.11 Properties assumed in generic concrete block permeable paving design in Table 20.10

Material	Elastic modulus (MPa)	Structural layer coefficient for use in ICPI (2011)	Poisson's ratio
Permeable pavers on a 50 mm bedding layer that meets requirements of BS 7533-13:2009	1000 (based on Shackel *et al*, 2000). Note that evidence from Knapton (2008) is that the modulus of the surface layer has very little effect on the predicted stress on the subgrade and performance of the pavement. Increasing elastic modulus values of the surface layer to justify a reduction in pavement depth is not normally recommended, as it requires extremely high construction quality, and there is no guarantee that all the joints will be completely full of jointing material for the life of the pavement to maintain an elevated elastic modulus.	0.3	0.40
AC32	6000	0.3–0.44	0.30
HBCGA (hydraulically-bound CGA) meets requirements of cement bound material category 3 (CBGM3) clause 800 series (DfT, 1998)	4000	0.24	0.25
Sub-base – coarse graded aggregate in accordance with BS 7533-13:2009	1000 Note that the main factor that affects stiffness is not the Los Angeles test (LA test) value but the grading and angular nature of the particles	0.09	0.35
5% CBR subgrade	50	n/a	0.45

Porous sports surfaces

Porous sports surfaces are usually not heavily trafficked by vehicles. An important issue for surfacing and sub-base layers used under sports pitches and games areas is that they meet the requirements of the relevant sporting federations for ball bounce etc. Most suppliers of artificial or turf surfacing will have this data or will test completed installations to demonstrate compliance. They also need to meet strict tolerances on surface levels. Usually the sub-base construction required to achieve these other requirements will be sufficient to support the likely vehicle loads (eg from maintenance vehicles).

20.10 PHYSICAL SPECIFICATIONS

20.10.1 Pre-treatment and inlets

Rainfall normally finds its way through the pervious surface via direct infiltration. However, where the pavement has sufficient hydraulic capacity, additional runoff from adjacent impermeable areas can be directed onto the pervious surface. The flow of water from the surface of adjacent paved areas should be distributed along the edge of the permeable area; it should not be channelled to a discrete point as this will cause clogging of the surface.

Runoff from adjacent roof areas can be drained directly into the sub-base, where it is likely to have very low levels of silt. However, such flows should be discharged via a silt/debris trap to prevent any risks of clogging of the pavement construction below the surface. The flow should be distributed into the sub-base using a diffuser such as the one in **Figure 20.24**.

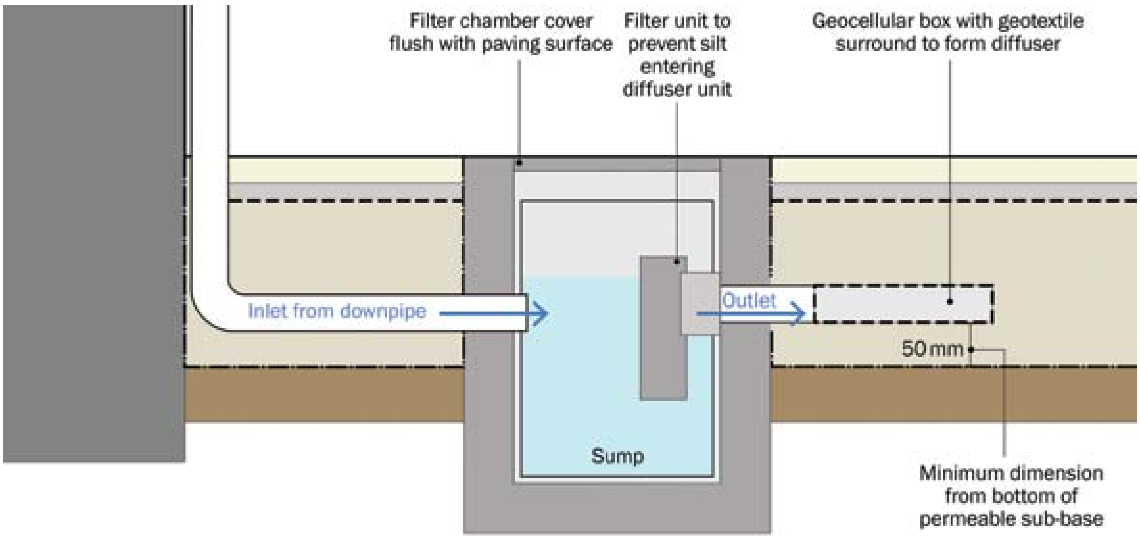

Figure 20.24 Flow diffuser to distribute roof runoff into permeable sub-base (from Interpave, 2013)

Where syphonic drainage is discharged into the sub-base, the siphon break should be before entry into the permeable sub-base via a ventilated manhole. The siphon break should be designed to provide sufficient capacity and to reduce flow velocities within the sub-base to prevent surcharging of the system. The siphon break and subsequent diffusers to distribute the flow into the sub-base should be designed in conjunction with the syphonic drainage designer.

20.10.2 Outlets

If the pavement is a Type A system that is designed to allow all water to infiltrate into the ground, there is no need for any specific outlet. If the system is a Type B or Type C, where water leaves the sub-base to flow to the next part of the drainage system, an outlet is required from the sub-base. This is usually achieved using either a series of perforated pipes (which can be within the sub-base or in trenches below (**Figure 20.25**), depending on the thickness of the sub-base and traffic loads and the strength of the pipes), or with a length of fin drain along one edge of the sub-base connected to the outlet pipe (**Figure 20.26**).

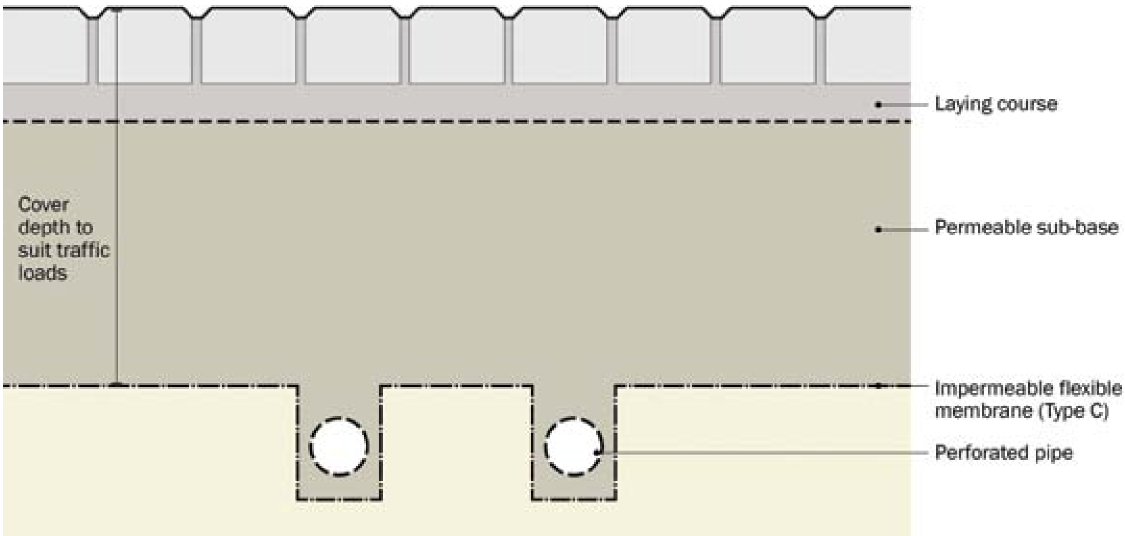

Figure 20.25 Perforated pipe outlets below sub-base

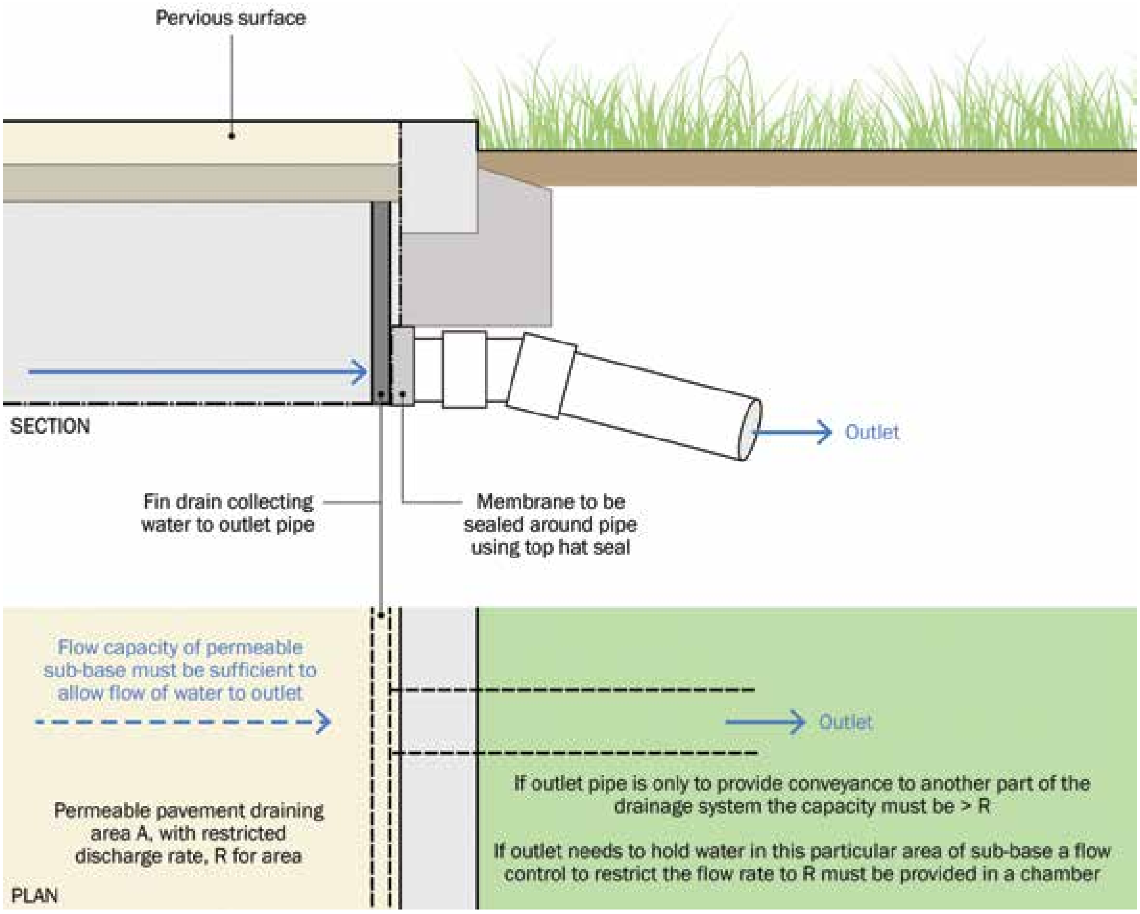

Figure 20.26 Fin drain outlet from pervious surface sub-base (from Interpave, 2010)

A well-protected observation well consisting of a 150 mm perforated pipe, or equivalent, should be placed at the downstream end of the facility. The well can be used to measure the actual emptying times of the pavement system and to keep a record performance changes with time.

20.11 MATERIALS

The sub-base beneath pervious surfacing systems has a large proportion of interconnected voids through which water can move freely and can also be stored. This material is different from a standard pavement sub-base and has to be specified so that it has sufficient permeability, porosity, strength and resistance to abrasion.

This section provides specifications for some of the key elements of pervious surfaces such as bedding and jointing material and sub-base. It does not provide a comprehensive specification for all elements that are required to meet recognised standards (eg the concrete blocks in concrete block permeable paving should meet all the same performance standards as normal concrete blocks).

20.11.1 Bedding layer and jointing material for concrete block permeable paving

Bedding and jointing material needs to be free-draining and have sufficient durability to resist wear from small movements between blocks. A typical grading specification is given in Table 20.12, but advice should always be sought from the pervious pavement manufacturer with regard to the exact material type that is suitable for each system. The jointing material in some systems may have smaller, 3 mm particles if the joints between blocks are smaller.

TABLE 20.12 Bedding and jointing layer specification (2/6.3 to BS 7533-13:2009)

BS sieve size (mm)	Percentage passing
14	100
10	90–100
6.3	80–99
2.0	0–20
1.0	0–5

The material should also meet the durability requirements in BS 7533-13:2009 (Section 20.11.4).

20.11.2 Sand infill and bedding layer for grass reinforcement

Sand infill to reinforced grass systems needs to be free-draining but with sufficient organic content to support plants. A root zone material (Chapter 30) is suitable, and there are also many other mixes recommended by suppliers of the grids. Normal topsoil is not suitable.

20.11.3 Geotextile filter characteristics

Geotextiles that act as filters should allow free flow of water, that is with zero breakthrough head. They should be manufactured from polyethylene, polypropylene or other suitable monofilament that can withstand the loads applied during construction and should have a design life equivalent to the pavement design life. They should not be adversely affected by pollutants, alkaline or acidic groundwater.

Geotextiles placed high in the pavement construction (eg between the bedding layer and sub-base of CBPP) are subject to higher stresses than those deeper in the construction (eg at the bottom of the sub-base). This needs to be evaluated and considered in the design.

▶ Further guidance on geotextiles is given in Chapter 30.

20.11.4 Sub-base aggregate characteristics

The sub-base should have a minimum porosity that is consistent with the design calculations (normally at least 30%). The sub-base should also have a minimum permeability of 6×10^{-2} m/s when tested in accordance with HA (1990).

The requirement for low fines content means that the surface loading will essentially be carried by point-to-point contact between aggregate particles in the sub-base. In order to maximise the friction between particles and thus increase strength, the particles should be rough and angular to give good interlock. Crushed rock (granite, basalt, gabbro) or concrete with > 90% fracture faces, or blast furnace slag is required to achieve this. Sand and gravel with rounded particles should not be used in pervious pavement sub-base construction. Aggregates should comply with BS EN 13242:2002+A1:2007 or BS EN 12620:2002+A1:2008. The choice is a compromise between stiffness, permeability and storage capacity. Typical gradings for sub-base aggregates are provided in **Table 20.13**. The material types are from BS 7533-13:2009 and from DfT (1998) Clause 805 Type 3 base material. However, there is no reason why other gradings cannot be used if they are more readily available and meet all the necessary requirements, and provided the base material is sufficiently durable.

TABLE 20.13 Typical grading requirements for sub-base aggregates (after BS 7533-13:2009 and DfT, 1998)

Sieve size (mm)	Percent passing		
	Coarse aggregate 4–40 mm (4/40) (BS 7533-13:2009)	Coarse aggregate 4–20 mm (4/20) (BS 7533-13:2009)	Type 3 sub-base 0–40 mm (0/40) (DfT, 1998)
80	100	–	100
63	98–100	–	80 -99
40	90–99	100	50–78
31.5	–	98–100	31–60
20	25–70	90–99	18–46
10	–	25–70	10–35
4	0–15	0–15	6–26
2	0–5	0–5	0–20
1	–	–	0–5

As the sub-base will be in contact with water for a large part of the time, the strength and durability of aggregate particles when saturated and subject to wetting and drying should be assessed. The materials should also not crush or degrade, either during construction or in service. The specification of LA test values, micro deval tests and flakiness tests will address these issues. Sub-base aggregate specification requirements are summarised in **Table 20.14**. This table is from BS 7533-13:2009 for CBPP but should be applied to sub-base materials used below all types of surfacing and also for Type 3 material and for recycled materials. Note that these durability requirements are as, if not more, important than the grading and should not be ignored.

Recycled material can be used where a source is conveniently available but care should be taken that this is of consistent quality, has an appropriate grading and is free of unacceptable materials such as organic matter or steel scrap. Leachate from crushed concrete sub-base material is likely to have a high pH value, which could impede vegetation growth and thus lead to soil erosion at the drain outlet and/or cause the growth of precipitates at the drain outlet. Therefore, outlets from recycled concrete sub-bases below pervious surfaces should be designed to minimise blockage by having a large surface area through which water is collected, and the outlets should be accessible to remove build-up or precipitates.

TABLE 20.14 Sub-base aggregate specification requirements (after BS 7533-13:2009)

Properties	Category to BS EN 13242:2002 or BS 12620:2002
Grading	Grading 4/40, Gc 85-15, GTc 20/17.5
Fines content	f4
Shape	FI_{20}
Resistance to fragmentation	LA_{30}
Durability:	
▪ water absorption to BS EN 1097-6:2000, Clause 7	WA242
▪ for WA.2%, magnesium sulphate soundness	MS_{18}
Resistance to wear	MDE_{20}
Acid-soluble sulphate content:	
▪ aggregates other than air-cooled blast-furnace slag	AS0.2
▪ air-cooled blast-furnace slag	AS1.0
Total sulphur:	
▪ aggregates other than air-cooled blast-furnace slag	≤ 1% by mass
▪ air-cooled blast-furnace slag	≤ 2% by mass
Volume stability of blast-furnace and steel slags:	
▪ air-cooled blast-furnace slag	Free from dicalcium silicate and iron disintegration (BS EN 13242:2002, 6.4.2.2)
▪ steel slag	V5
Leaching of contaminants	Blast furnace slag and other recycled materials should meet the requirements of the Environment Agency Waste Acceptance Criteria (WAC) for inert waste when leachate tested in accordance with BS EN 12457-3:2002

Note that both the resistance to wear and resistance to fragmentation are important. The LA test is an indication of the resistance to fragmentation and can only be carried out on dry aggregate. The Micro-Deval test (MD test) measures the resistance to abrasion when interlocking particles are subject to repeated loading in the presence of water which is an important property for sub-bases below pervious pavements.

Impermeable membrane characteristics

These are typically manufactured from high density polyethylene (HDPE), polypropylene or ethylene propylene diene monomer rubber (EPDM) and should be:

- durable, robust and able to withstand construction and operational loads
- resistant to puncture, multi-axial stresses and strains associated with movement and environmental stress cracking (or protected by geotextile or sand layers above and below as required – the greatest risk of puncture is often from the sub-base material laid on top of the membranes)
- unaffected by potential pollutants
- installed with fully watertight joints and discharge outlets. Welded joints should be tested to ensure the integrity of the system and provide a more robust jointing method. The membrane should be able to resist the punching stresses caused by sharp points of contact from the aggregate sub-base. It should also have sufficient strength to resist the imposed tensile forces from traffic or other loading. Where the risks associated with puncture are particularly high, consideration can be given to protecting membranes with geotextile fleeces.

▶ Further guidance on geomembranes and geotextiles is given in **Chapter 30**.

Porous asphalt

Example specification requirements for porous asphalt are provided by Korkealaakso (2014).

The surface infiltration rate (or permeability) for porous asphalt quoted by Korkealaakso (2014) are based on measurement using the test method described in Series 900 of DfT (1998). However, it is recommended that for consistency in future, the surface permeability of porous asphalt is measured using the same method as porous concrete from ASTM C1701M-09, although the specification limits would require amending to reflect the different test method.

Porous concrete

A specification for porous concrete is provided by CRMCA (2009).

The key requirements are:

- compressive strength – specified by pavement designer, typically between 3 MPa and 27 MPa (FHA, 2012)
- cement content 267–326 kg/m^3
- porosity 15–25%
- water:cement ratio 0.26–0.35.

Also to the requirements in the CRMCA specification it is recommended that the surface infiltration rate is a minimum of 250 mm/h when measured in accordance with ASTM C1701M-09.

20.12 LANDSCAPE DESIGN AND PLANTING

Permeable pavements do not often support vegetation as part of the surfacing (except for grass reinforced pavements), but the landscape can be designed and integrated either around the edge of pavement systems, or in zones within the pavement surface layout.

If trees or woody shrubs are desired, they should be carefully selected. If trees and shrubs are planted close to permeable paving it may require more regular sweeping to maintain the surface infiltration rate, although this is not likely to be excessive.

Permeable pavements are an excellent form of construction near trees, because they allow air and water to enter the soil, which is beneficial to tree growth. If tree roots have sufficient water and air in the soil, they are unlikely to damage the permeable pavement construction.

Where grass is an intrinsic part of the porous surface (eg **Figure 20.8**), it should be established before trafficking, and the surface should be kept free of sediment until the grass is established. The choice of grass is important, and it should have a high tolerance to wear and drought, and a low tendency to thatch build-up (for planting guidance, see **Chapter 29**). Where reinforced grass is used, it is important to make sure that the infill soil is lower than the grids.

Wherever possible, it is suggested that areas in and around pervious pavements should have a topsoil level that is at least 50 mm below the top of the kerb adjacent to the pervious pavement. Preferably, the areas should slope away from the pervious pavement (**Figure 20.27**). Where areas drain onto a pervious pavement, their surfaces should be stabilised so that the mobilisation of silt and other fine debris is minimised.

If this cannot be achieved (but there are many examples of permeable paving working satisfactorily next to standard landscapes), the risk of clogging should be minimised through more frequent sweeping regimes. The required frequency of sweeping should be established through visual monitoring of the surface, particularly following intense rainfall.

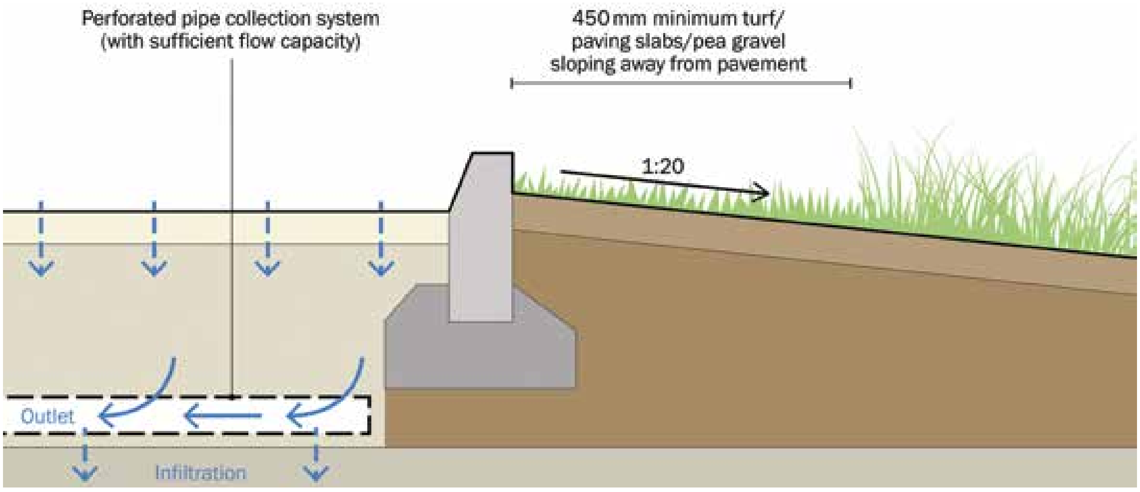

Figure 20.27 Landscape detail for pervious pavement

Figure 20.28 Hotel car park with grass-reinforced concrete blending into the surrounding landscape, Cambridgeshire (courtesy Peterborough City Council)

20.13 CONSTRUCTION REQUIREMENTS

The principles of good construction that apply to asphalt, standard concrete block paving and other impermeable surfaces generally also apply to pervious pavements. The following guidance should also be considered when constructing a pervious pavement structure. The list is in order of construction – from the subgrade upwards.

20.13.1 Subgrade

Proof rolling of the formation below Type A and B pervious pavements is not recommended as it can reduce the infiltration rate of the soil. Subgrade soft spots can be identified using a hand-held MEXEcone or similar (ie an instrument to measure *in situ* CBR values). If soft spots are identified, they should be excavated and backfilled with suitable well-compacted material and, for Type A pavements, the materials should be of similar permeability to the surrounding subgrade.

The formation should be prepared by trimming to level in accordance with DfT (1998), to a tolerance of +20 to −30 mm. If subgrade improvement is employed, testing will be needed to demonstrate that the design CBR values have been consistently achieved and, for Type A pavements, that the infiltration rate of the soil is suitable.

The formation below Type A pavements should be protected from any operations that could reduce the infiltration rate of the soil (eg heavy construction traffic, stockpiling fine materials, mixing concrete on it).

20.13.2 Geomembrane and/or geotextile

Any impermeable membrane should be correctly specified, installed and treated with care to ensure that it is not damaged during construction (**Chapter 30**).

Geotextiles should be laid in accordance with manufacturers' instructions and with overlaps between adjacent strips of 300 mm without any folds or creases. It is recommended that specialist advice be sought from the manufacturer or supplier of the geosynthetic filter (**Section 20.11.3**).

20.13.3 Capping layer and sub-base

The fines in a conventional impermeable material help to bind the different size particles together, and act to restrict the passage of water. In the case of pervious pavement materials (which lack fines), there is potential for segregation of materials during the transportation and construction process. Care should be taken to avoid segregation, but the material should be turned over by an excavator if this occurs. The risk of segregation can be minimised by using an angular, crushed material with high surface friction.

The lack of fines and the open matrix structure can result in surface movement when construction traffic passes over the sub-base, and it can be more difficult to form to the required grades. This movement can be minimised by blinding the surface with a laying course or other smaller size aggregate to fill in the voids at the surface and stabilise it. The depth of the sub-base should be adjusted to include this blinding layer.

The sub-base should be laid in 100–150 mm layers and compacted to ensure that the maximum density is achieved for the particular material type and grading, without crushing the individual particles, or reducing the porosity below the design value. There should be a tolerance of +20 to −15 mm on the design surface level of the sub-base layer. Compaction with vibrating rollers can be difficult, as it results in movement of the surface and often dead-weight rollers are more effective. Site trials are the best way to determine the appropriate compaction method.

Once laid, the sub-base should not be trafficked. This is to prevent it rutting and also to prevent it clogging with mud and other construction materials. If it has to be trafficked, it should be protected using one of the following methods:

- a layer of DBM that can then be allowed for as part of the structural design of pavement (**Section 20.9**) – this should be punctured with 75 mm diameter holes, on an orthogonal grid of 750 mm (**Figure 20.29**)
- a geotextile and sacrificial aggregate layer – removed before laying final blockwork
- for Type C pavements only, a normal capping layer for construction and then construct the pervious surface once its use as a construction surface is no longer required.

Base

HBCGA should not be mixed in concrete mixers on site. It needs to be produced in batching plants or mixed at the quarry. Careful mixing is required because of the low cement content, and there is a need to ensure that it is evenly spread throughout

Figure 20.29 Layer of protective DBM over sub-base after coring and before laying concrete block permeable paving (courtesy Peterborough City Council)

the material and not segregated. Laying HBCGA should not be carried out in weather that is too hot, or in heavy rain. The guidance provided by ACPA (2011) on laying porous concrete surfacing should be followed as it is applicable to HBCGA.

Asphalt base materials should be laid in accordance with DfT (1998).

Surfacing

Generally, concrete block pavements should be constructed in accordance with current industry guidance such as that provided by UK-based manufacturer and contractor associations (eg Interpave and Interlay). Advice should be sought from the specific manufacturer on any product-specific requirements, laying and jointing materials, block patterns and block laying procedures. In accordance with good practice, the block surface layer should be fully compacted and jointed to within 1 m of the laying face at the end of each day. Other pavement surfaces should be constructed according to the relevant British Standards and/or the manufacturer's guidance.

Once concrete blocks are laid on the screeded bedding layer they should be vibrated into the bedding layer. This causes grit to fill the lower part of the joints. Grit should be brushed into the top of the joints and the blocks vibrated again. There may be settlement of grit in the joints over the first few months of use and it is wise to allow for the blocks to be gritted again after a few months in service.

Porous concrete used as a surfacing may need joints forming in it. The ACPA recommends that the joints are not formed by saw cutting, as this leads to dust-blocking of the adjacent areas of surfacing. The joints should be formed using a "pizza cutter" roller before the concrete has set. Compaction of the porous concrete (and HBCGA) should be undertaken using rollers and not vibrating plate compactors.

Porous asphalt should be laid in accordance with DfT (1998).

Resin-bound gravel should be laid in accordance with the manufacturer's recommendations.

For grass reinforcement systems, the bedding sand thickness should be kept to a minimum. A maximum thickness of 20 mm is recommended. It is difficult to cut grass reinforcement systems of any kind to fit complicated shapes without loss of integrity. This should be considered in the design and construction. The grass grids should not be overfilled with soil because it leads to compaction, and the grass will not grow. At least 25 mm depth should be left between the top of the grid and the infill soil. For optimum vegetation coverage the paver or grid needs to have in excess of 30% of its area available for grass growth. Concrete pavers can be heavy and may need to be machine laid. Unless product-specific skid resistance data is available, they should only be used in low-speed situations. Sometimes concrete grass grids will crack due to uneven support in the bedding sand or sub-base, but once it is cracked, the paver will bed into the sand and will usually continue to provide support to traffic. Plastic grids need expansion joints or allowance for movement in the construction as they can expand and buckle in hot weather.

Preventing soil and mud and other contaminants from entering the pavement surface, sub-base and subgrade, both during and after construction, is imperative to ensure that the pavement remains permeable throughout its design life. Construction equipment should be kept away from the area, and silt fences, staged excavation works and temporary drainage swales (which divert runoff away from the area) should all be considered to manage these risks. Landscaping activities should be carefully designed and carried out to prevent deposition of topsoil, turf and other materials on the surface of the pavement. Infiltration surfaces should not be compacted and should be protected at all times.

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety considerations are presented in **Chapter 36**.

20.14 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is important for the effective operation of pervious pavements. Maintenance responsibility for a pervious pavement and its surrounding area should be placed with an appropriate responsible organisation. Before handing over the pavement to the client, it should be inspected for clogging, litter, weeds and water ponding, and all failures should be rectified. After handover, the pavement should be inspected regularly, preferably during and after heavy rainfall to check effective operation and to identify any areas of ponding.

Pervious pavements need to be regularly cleaned of silt and other sediments to preserve their infiltration capacity. Extensive experience suggests that sweeping once per year should be sufficient to maintain an acceptable infiltration rate on most sites. However, in some instances, more or less sweeping may be required and the frequency should be adjusted to suit site-specific circumstances and should be informed by inspection reports.

A brush and suction cleaner (which can be a lorry-mounted device or a smaller precinct sweeper) should be used for regular sweeping. Care should be taken in adjusting vacuuming equipment to avoid removal of jointing material. Any lost material should be replaced. It is also possible to clean the surface using lightweight rotating brush cleaners combined with power spraying using hot water, as shown in **Figure 20.30**. This is done every two years at the site shown.

If the surface has clogged then a more specialist sweeper with water jetting and oscillating and rotating brushes may be required, especially for porous asphalt surfaces, to restore the surface infiltration rate to an acceptable level. The specialist equipment should be adjusted so that it does not strip binder from the aggregate in the asphalt.

Figure 20.30 Deep cleaning a supermarket car park, Dundee (courtesy Abertay University)

The likely design life of grass reinforcement will be dictated by trafficking and is likely to be about 20 years if designed correctly. For concrete block permeable paving the design life should be no different from standard paving, assuming that an effective maintenance regime is in place to minimise risks of infiltration clogging. Porous asphalt will lose strength and begin to fatigue due to oxidation of the binder. This is likely to occur slightly faster in porous asphalt than normal asphalt, so the design life will be reduced slightly. Porous concrete should have a similar design life to a normal concrete slab.

The reconstruction of failed areas of concrete block pavement should be less costly and disruptive than the rehabilitation of continuous concrete or asphalt porous surfaces due to the reduced area that is likely to be affected. Materials removed from the voids or the layers below the surface may contain heavy metals and hydrocarbons and may need to be disposed of as controlled waste. Sediment testing should be carried out before disposal to confirm its classification and appropriate disposal methods.

▶ Guidance on waste management is provided in **Chapter 33**.

Table 20.15 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

Maintenance Plans and schedules should be prepared during the design phase. Specific maintenance needs of the pervious pavement should be monitored, and maintenance schedules adjusted to suit requirements.

▶ Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

TABLE 20.15 Operation and maintenance requirements for pervious pavements

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Brushing and vacuuming (standard cosmetic sweep over whole surface)	Once a year, after autumn leaf fall, or reduced frequency as required, based on site-specific observations of clogging or manufacturer's recommendations – pay particular attention to areas where water runs onto pervious surface from adjacent impermeable areas as this area is most likely to collect the most sediment
Occasional maintenance	Stabilise and mow contributing and adjacent areas	As required
	Removal of weeds or management using glyphospate applied directly into the weeds by an applicator rather than spraying	As required – once per year on less frequently used pavements
Remedial Actions	Remediate any landscaping which, through vegetation maintenance or soil slip, has been raised to within 50 mm of the level of the paving	As required
	Remedial work to any depressions, rutting and cracked or broken blocks considered detrimental to the structural performance or a hazard to users, and replace lost jointing material	As required
	Rehabilitation of surface and upper substructure by remedial sweeping	Every 10 to 15 years or as required (if infiltration performance is reduced due to significant clogging)
Monitoring	Initial inspection	Monthly for three months after installation
	Inspect for evidence of poor operation and/or weed growth – if required, take remedial action	Three-monthly, 48 h after large storms in first six months
	Inspect silt accumulation rates and establish appropriate brushing frequencies	Annually
	Monitor inspection chambers	Annually

Many of the specific maintenance activities for pervious pavements can be undertaken as part of a general site cleaning contract (many car parks or roads are swept to remove litter and for visual reasons to keep them tidy) and therefore, if litter management is already required at site, this should have marginal cost implications.

Generally, pervious pavements require less frequent gritting in winter to prevent ice formation. There is also less risk of ice formation after snow melt, as the melt water drains directly into the underlying sub-base and does not have chance to refreeze. A slight frost may occur more frequently on the surface of pervious pavements compared to adjacent impermeable surfaces, but this is only likely to last for a few hours. It does not happen in all installations and, if necessary, this can be dealt with by application of salt. It is not likely to pose a hazard to vehicle movements.

▶ Generic health and safety guidance is presented in **Chapter 36**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

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ASTM C1701M-09 *Standard test method for infiltration rate of in place pervious concrete*

ASTM C1781M-13 *Standard test method for surface infiltration rate of permeable unit pavement systems*

Image courtesy Polypipe

21 ATTENUATION STORAGE TANKS

Contents

Chapter
21

Attenuation storage tanks

This chapter provides guidance on the design of attenuation storage tanks – structures that create a below-ground void space for the temporary storage of surface water before infiltration, controlled release or use.

21.1 GENERAL DESCRIPTION

Attenuation storage tanks are used to create a below-ground void space for the temporary storage of surface water before infiltration, controlled release or use. The storage structure is usually formed using one of the following methods:

- geocellular storage systems
- plastic corrugated arch structures (constructed over and backfilled with an open-graded aggregate base)
- oversize concrete pipes
- oversize plastic pipes
- corrugated steel pipes
- precast or *in situ* concrete box culvert sections and tanks (including flat-packed concrete panels)
- glass-reinforced plastic (GRP) tanks
- hybrid structures using reinforced earth walls and concrete roof panels

There are other types of tank system available, but these are not as commonly used and are covered by general construction specifications and design requirements. These are not discussed in detail in this chapter.

The inherent flexibility in size and shape (and in some cases modularity) of the above systems means that they can be tailored to suit the specific characteristics and requirements of any site. Their main benefits are:

1 their high storage volume (compared to structures filled with aggregates)
2 their potential for installation beneath roads and car parks (provided they are designed to withstand traffic loadings) and recreational areas and other public open space.

Important considerations are:

1 level of accessibility and maintainability with some types of system
2 lack of treatment performance when used in isolation
3 cost (compared to surface systems, assuming that these can be implemented in public space, that is without requiring extra land-take).

These systems can be designed for use under areas trafficked by HGVs and other heavy plant, such as at ports and airports, but it should be noted that their use under public (or adopted) roads will generally be subject to technical approval by the relevant highway authority. This should be sought at an early stage in the design process.

The maintainability of attenuation tank storage systems requires careful consideration. They lie beneath the ground, so any failures or blockages will tend not to be noticed, which may increase risks to the site. Geocellular systems and plastic arches tend not to be easily accessible for inspection or cleaning, so very effective upstream treatment is required to ensure adequate sediment removal. There are some systems that incorporate "access" tunnels or a more open structure. However, in practice these only provide limited access, and it is difficult to see beyond the tunnels or to manoeuvre CCTV cameras within the tanks. Unless surface access points are provided for every tunnel, access for jetting is also limited.

All of these systems require integration with the overall surface water treatment strategy, as they do not have inherent treatment capability. They can be space-efficient, owing to the potential for use of the land above the tanks, but as they are structural systems, the cost of installation will tend to be high compared to storage systems on the surface.

Most of the methods of providing attenuation are well understood in terms of structural design/performance (ie pipes and arches in various materials and culverts). The structural design of geocellular systems tends to be more complex and there have been a number of collapses of these systems caused by inadequate design (see Mallett *et al*, 2014, and O'Brien *et al*, in press). Therefore, this chapter provides more detail on the structural design of this type of tank structure than others, although many of the issues are relevant to all methods.

Many of the products used to form attenuation tanks can also be used to provide the temporary storage required for infiltration systems (**Chapter 13 and Chapter 25**).

21.1.1 Geocellular storage systems

Geocellular storage systems are modular plastic units with a high porosity (generally around 95%) that can be used to efficiently create a below-ground structure for the temporary storage of surface water before controlled release or use. The storage structure (tank) is formed by assembling the required number of individual units (sometimes in several layers), and wrapping them in either a geotextile or a geomembrane.

Geocellular systems have been used in Europe since 1987 (Le Nouveau *et al*, 2007) in place of stone-filled soakaways, concrete tanks or oversized pipework. They are light and easily installed without heavy machinery, which can lead to time and cost savings in construction (**Figure 21.1**).

If the flow characteristics of the geocellular unit are sufficiently well characterised by hydraulic testing, they can also be used as a conveyance mechanism. Their inherent resistance to flow can also be used in the design to remove the need for flow controls on some sites (using measured head–discharge relationships and modelling).

Figure 21.1 Geocellular storage system under construction (courtesy Polypipe Limited)

The modular units have two basic components:

- The inner "structural frame" provides basic stiffness and strength and is delivered by the box unit (**Figure 21.2**).
- The outer "skin" keeps out soil and backfill, and is delivered by the geomembrane or geotextile (**Figure 21.3**).

Figure 21.2 Structural frame being constructed (courtesy EPG Limited)

Figure 21.3 Frame covered by outer skin (geomembrane in this case) (courtesy EPG Limited)

Geocellular units are not all the same. There are various types of box units that have different structural characteristics and load carrying capabilities. Geocellular systems can generally be categorised in terms of their structure type (O'Brien *et al*, in press) as follows:

1 injection-moulded units with internal columns/supports – completely assembled at the factory
2 injection-moulded units with internal columns/supports – assembled in site; there are an increasing number of injection-moulded geocellular systems that are manufactured in sections (typically two halves) that are stackable for ease of transport and then assembled on-site, with or without a mid-plate or outer faces to form a tank
3 sub-base replacement systems – this refers to a specific type of injection-moulded unit
4 open plate structures – box structures that are made from individual injection-moulded plates that are clipped or fitted together to form a box
5 open column structures – made from individual columns and roof/floor/side panels that are clipped or fitted together to form a tank or unit
6 plastic profiled sheet structures – box structures made from individual sheets of plastic that are glued or welded together, but note that many of these types of product were developed for use as trickle filter media in cooling towers or wastewater treatment works where they are known as structured sheet media
7 honeycomb structures.

There are other types of units available, and the above list is not exhaustive. Some units can be assembled on site, while others will be supplied in a fully assembled form. New types of unit are continually being introduced.

They can be designed and manufactured with a range of structural capacities to support loads from HGVs under areas such as lorry parks.

The direction of water flow through the units can vary, depending on the internal structure. In terms of hydraulic performance, the units can be classified as:

1 **three-dimensional, free flow** – water enters via inlet pipework and exits via outlet pipework which is connected to the sides of the completed structure. 3D water flow occurs in types 1 to 4 in the preceding list. These systems can also be designed to fill vertically from below in the same way as 2D systems (see below). A typical layout is shown in **Figure 21.4**
2 **two-dimensional, limited horizontal flow** – water enters via perforated distribution pipework running under, through or over the tank. At a critical flow threshold, water is forced out of the pipework, through a gravel layer and into the storage tank. Types 5 and 6 in the preceding list represent principally 2D flow systems. Typical sections through 2D systems for attenuation storage application are presented in **Figures 21.5 and 21.6**.

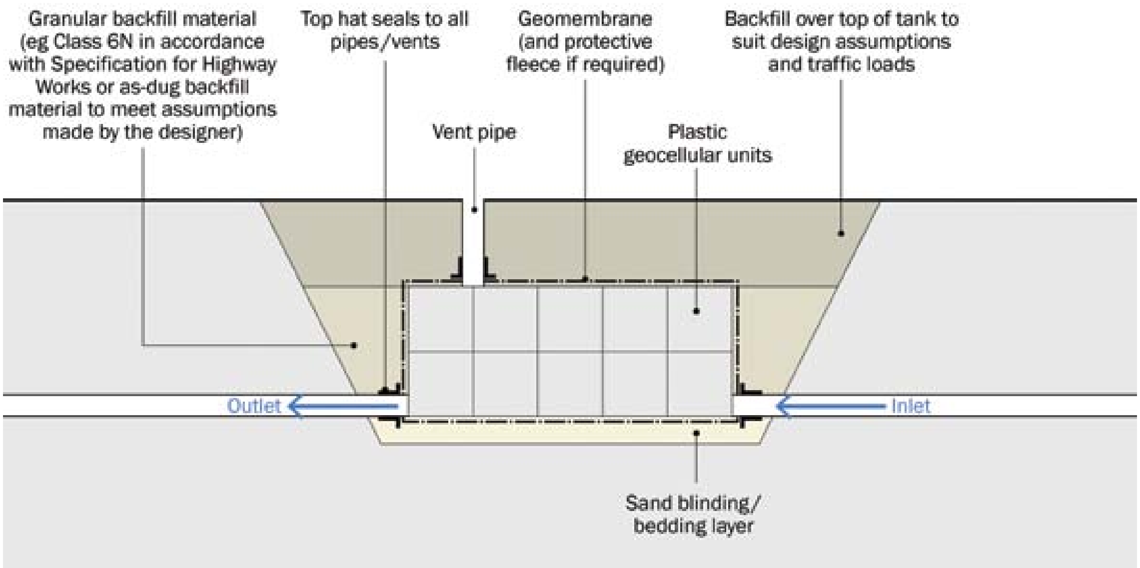

Figure 21.4 Schematic of 3D system in storage and attenuation mode

Horizontal water flow may be substantially restricted or even not possible with honeycomb units. It is therefore highly inadvisable to connect pipes directly to the side of the tank in the form of inlets or outlets. The most common form of inlet arrangement for these systems is to use a perforated pipe in gravel below the tank. When water backs up from the downstream flow control the water passes from the pipe, upwards into the tank; it then drains down in the opposite direction.

If a granular bedding of sufficient permeability is installed beneath the geocellular units as well as forming the pipe trench, then the arrangement in **Figure 21.7** can be used for all honeycomb systems as well as profiled sheet systems. The pipe bedding and surround should be of sufficient depth and width to provide support to the pipe, and the pipe should have sufficient strength and stiffness to support the vertical loads. This is especially important for plastic pipes because the geocellular units do not provide the same resistance to pipe deformation that the side walls of a trench in soil would do.

Some honeycomb systems allow limited horizontal flow and therefore this arrangement could also be used for these system types as long as the horizontal flow capacity is sufficient to accept the design flows.

Profiled plastic sheets will normally allow horizontal water flow in one direction only. In some cases, the units do have limited horizontal water flow capacity perpendicular to the main horizontal flow direction. For this type of tank it is common to have inlets that operate via perforated pipes that are either located in a gravel-filled trench within the tank or are incorporated into the units themselves. If inlet velocities are low enough, pipes can be attached directly to the open end of the profiled sheet units. Pipes should not be attached to the sidewalls, where little or no lateral flow into the tank can occur.

All types of sealed system require a vent to dissipate air pressure as the tank fills. A common rule of thumb is to provide one 110 mm diameter air vent for every 7500 m^2 of catchment area draining to the tank. Complicated shapes should be avoided when designing these tanks, as they can increase the risk of sediment being trapped and also make the installation of any geomembrane more difficult – increasing the risk of leaks occurring.

Some manufacturers supply specific modules that are used as inspection and maintenance chambers or sediment forebays within the tank construction (**Figure 21.5**).

Figure 21.5 Man access chambers located within the structure (courtesy Aco Limited)

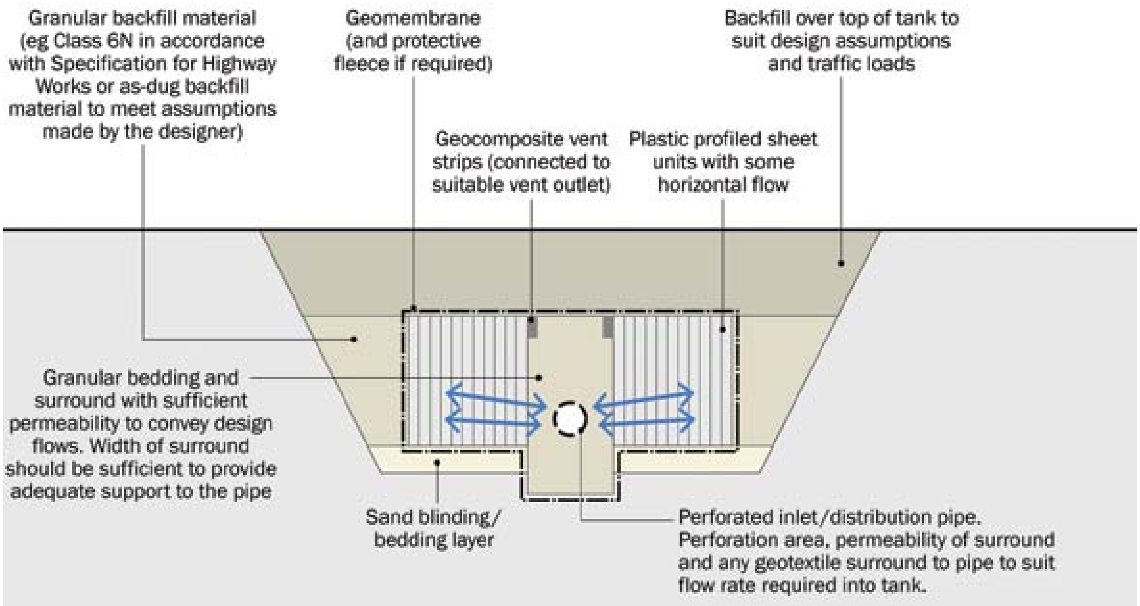

Figure 21.6 Schematic of 2D system in attenuation storage mode (central inlet pipe)

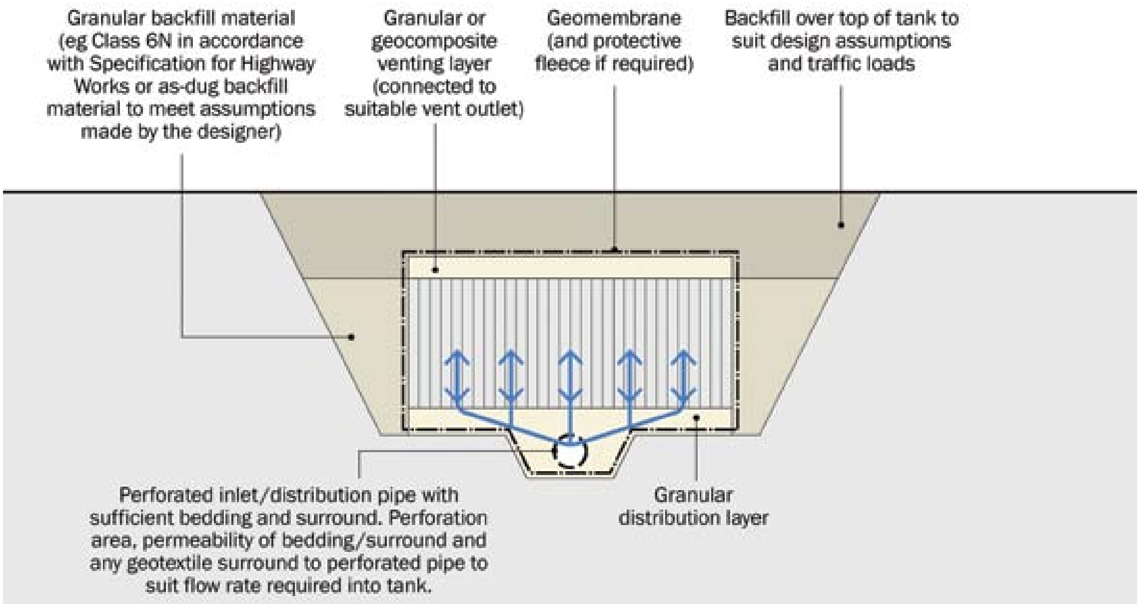

Figure 21.7 Schematics of 2D systems in attenuation storage mode (upflow filling)

21.1.2 Plastic corrugated arch structures

Plastic corrugated arch structures comprise plastic arches (made from high density polyethylene (HDPE) or polypropylene). The arches have an open bottom and are supported at the base by integral plastic feet that are laid on a bed of aggregate. The arches are backfilled with aggregate. They are usually laid in rows and are terminated at each end with end caps.

The arches can be perforated to allow water to flow out into the surrounding backfill. In this case, the backfill should be specified to provide sufficient porosity and permeability for the design.

The storage capacity in the system is a combination of the void space in the arches and that provided in any surrounding aggregate (if the arches are perforated).

A typical layout detail is provided in **Figure 21.8**.

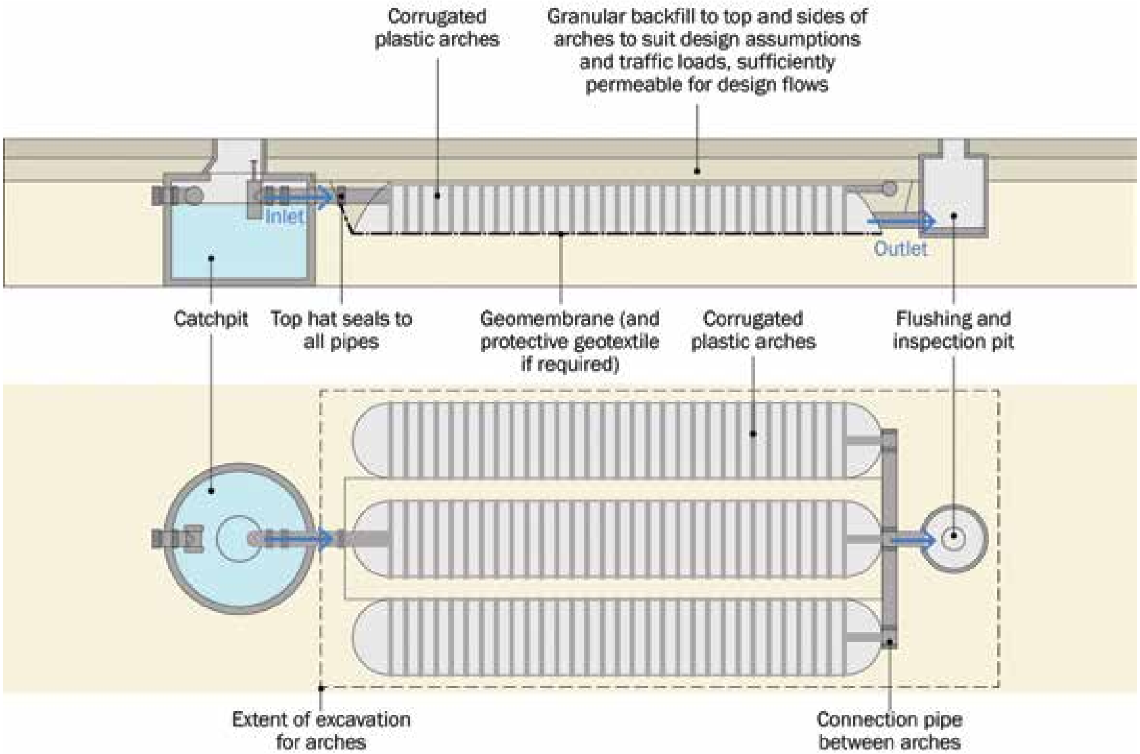

Figure 21.8 Typical layout of an arched system

The arches can be manufactured and designed to provide suitable load-bearing performance for different uses including heavy traffic (eg HGV).

If they have pipe connections directly into a row of arches, the space can be inspected and cleaned by jetting. However, if rows do not have a direct and suitable pipe connected into them, they cannot be easily accessed. Note that it is not really possible to get CCTV cameras and jetting equipment around right angle bends in small diameter pipes, so any access pipework requires suitable design.

In the layout in **Figure 21.8** only the central row of arches is really available for flushing/inspection. The floor of the system will be either formed of open gravel or it may be covered by a geotextile, and this is not likely to be durable if it is jetted frequently. If sediment is allowed to enter the surrounding gravel, it cannot be removed (which could be an issue with fine sediment fractions).

21.1.3 Oversize concrete pipes

Oversize concrete pipes have been used for many years as attenuation tanks, and are available in a wide range of standard sizes and shapes. The term oversize refers to the fact that they are larger than necessary for just conveying water, in order to provide storage. Details of all the different variations that are available are explained by CPSA (2013). They can easily be provided with direct access chambers for routine maintenance (**Figure 21.9**). The materials used are well understood and they have a very long service life. They can be designed to support loads from HGVs and other heavy traffic such as in port or airport installations. They can meet the necessary design standards for use under public roads.

Figure 21.9 Direct access chamber into concrete pipe (courtesy British Precast)

Elliptical concrete pipes can be designed that provide flexibility to fit concrete pipe solutions into areas where space or cover depth are limited. Some manufacturers offer factory-fitted or cast-in blank ends, which may be required if the tank is designed as an off-line storage system. Precast concrete pipes should be designed and manufactured to meet the requirements of BS EN 1916:2002 and BS 5911-1:2002+A2:2010.

A typical layout of a concrete pipe system is shown in **Figure 21.10**. A fall is usually provided in the oversize pipe, so an upstream catch pit may not be required if silts are collected and/or removed at the sump on the downstream flow control chamber. Concrete pipes are rigid and do not necessarily need a full granular surround, which can reduce the volume of imported materials required in the construction compared to flexible pipes.

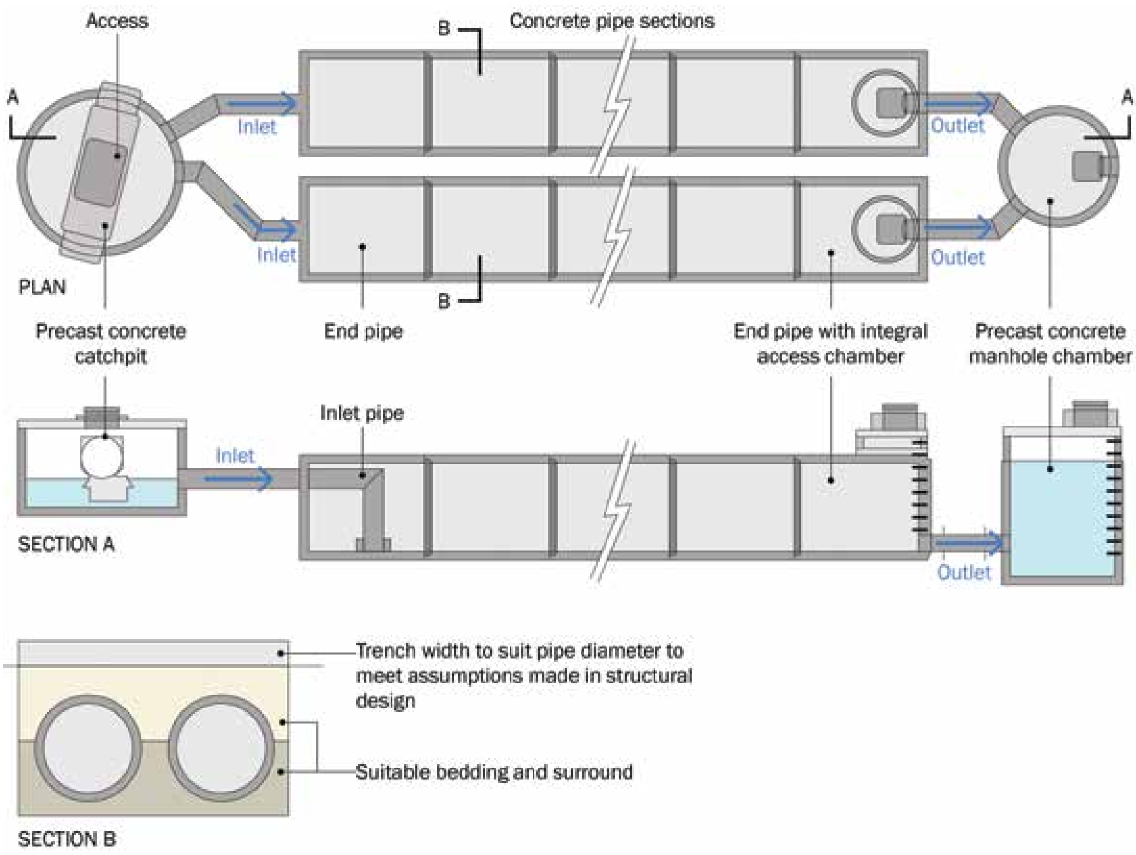

Figure 21.10 Typical layout of concrete pipe system

21.1.4 Oversize plastic pipes

Oversize plastic pipes are also used as attenuation tanks, and are available in a wide range of standard sizes – typically up to 3 m diameter. As with oversize concrete pipes, the term oversize refers to the fact that they are larger than necessary for just conveying water, in order to provide storage. They are usually available in 6 m sections. They can easily be provided with direct access chambers for routine maintenance (**Figure 21.11**). They can be designed and manufactured with a range of structural capacities, to support loads from, for example, HGVs under areas such as lorry parks and roads. The larger diameter plastic pipes are normally structured wall pipes with a smooth internal face and are manufactured from HDPE or polypropylene.

Plastic pipes may allow the use of smaller plant to lift and place them than the same diameter pipes made from heavier materials. The lighter weight of plastic pipes compared to other materials needs to be taken into account when assessing the risk of floatation if constructed below groundwater.

Figure 21.11 Installation of oversized plastic pipe attenuation tanks (courtesy Polypipe Limited)

The 6 m lengths give a reduced number of joints, which can reduce the risk of leakage occurring. The joints can be conventional spigot and socket, or the pipes can be welded together (hand extrusion or electro-fusion welding). They can also be provided with bespoke chambers and access points into the pipes.

The general layout will be similar to that for concrete pipes (shown in **Figure 21.11**), although the precise details of bedding etc will be specific to plastic pipes, which normally require a full surround of granular bedding material (Class S).

21.1.5 Corrugated steel pipes

Corrugated steel pipes are used to construct tanks in a similar way to plastic and concrete pipes. The performance of these materials is well understood, and they have been in use for many years. They are typically available in diameters up to 3.6 m and can be designed to suit loads including HGV traffic under areas such as motorways and other heavily loaded areas, such as ports and airports. They can meet the necessary design standards for use under public roads.

The pipes are usually galvanised with a zinc coating on the internal and external surfaces, which should provide a design life of up to 60 years in suitable conditions. The chemistry of the ground should be assessed to determine their likely durability, but if necessary they can also be coated with a protective secondary coating of a polymer, to increase resistance to aggressive ground conditions. They are often prefabricated to include access shafts, and are likely to have gasket joints. A typical tank is shown in **Figure 21.12**.

It might be possible that zinc can leach from galvanised pipes and cause pollution of the surface water runoff (Ogburn, 2013). The significance of this will depend on the pH of the runoff, the volume-to-surface-area ratio of a tank and the contact time with the tank walls. If necessary a protective secondary coating can be applied or a bitumen paved invert provided to prevent this. Additives can also be added to the zinc coating to reduce dissolution.

Figure 21.12 Typical corrugated steel tank under construction (courtesy Tubosider UK Limited)

Figure 21.13 Precast concrete box culvert being installed as part of a SuDS scheme (courtesy British Precast)

21.1.6 Concrete box culvert/tank

Precast concrete box culverts are available in a wide range of standard sections. They can come with end walls, access shafts and preformed inlets and outlets. They can also have dry weather flow channels formed in the base if needed. The joints are normally spigot and socket joints that are sealed using jointing strips (eg rubber bitumen). The materials used are well understood, and they tend to have a very long service life. They can be designed to support loads from HGVs and other heavy traffic such as in port or airport installations. They can meet the necessary design standards for use under public roads. They are readily accessible for maintenance to remove any sediment build-up.

Design and manufacturing requirements for box culverts are provided in BS EN 14844:2006+A2:2011. Box culverts manufactured to BS EN 14844 should be monolithic in structure.

Concrete tanks can also be constructed using precast concrete panels that are assembled on site to form the tank (known as flat pack tanks) or using cast-*in situ* concrete.

21.1.7 Glass-reinforced plastic (GRP) tanks

GRP tanks are usually manufactured as a complete tank unit including all access shafts and inlets/outlets. They are available in a range of sizes, typically up to about 300,000 litres. They can also be laid side by side and interconnected to form larger tanks. The tanks are easily accessible for maintenance.

The absence of site jointing reduces the risk of leaks, and they provide a durable solution with a long service life. GRP tanks are frequently used as rainwater harvesting tanks (**Chapter 11**). The tank is normally placed on a concrete base and surrounded by either a concrete or granular backfill to achieve the required load-bearing capacity. They are quick and easy to install and can be placed below roads and similar areas with HGV traffic.

21.1.8 Hybrid tanks

Hybrid tanks use a combination of reinforced earth walls/abutments combined with reinforced concrete roof panels. Both elements are well understood construction methods that have been used successfully for many years in other applications. A typical layout is shown in **Figure 21.14.** The whole construction is surrounded by an impermeable geomembrane to form a tank.

The reinforced walls are constructed with open-graded stone to provide some of the storage capacity. This also prevents the build-up of excess pore pressure or uneven water pressure within the fill, and this helps maintain the stability of the system. Reinforced earth is a durable material that can be designed and constructed to provide a long design life.

The system provides a large open chamber that can be accessed for maintenance, although if silt enters

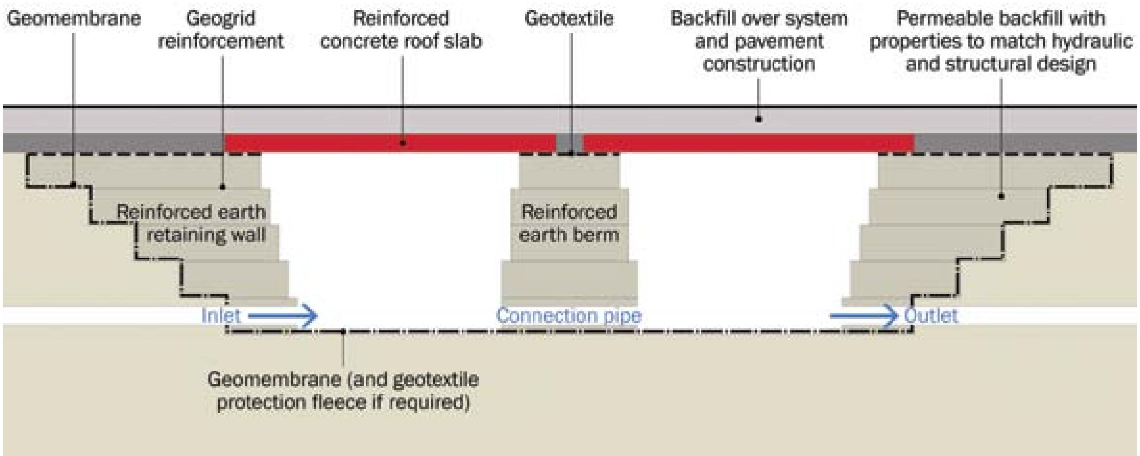

Figure 21.14 Typical layout of hybrid tank

the surrounding aggregate it will be difficult to remove.

These systems can be easily designed to support heavy loads such as HGVs and other heavier loads (eg at ports and airports). The materials used are very durable and will give a long service life, providing routine maintenance to keep sediment out of the gravel is undertaken.

Figure 21.15 Hybrid tank of reinforced earth and concrete roof panels (courtesy Stormwater Management)

21.2 SELECTION AND SITING OF ATTENUATION TANK SYSTEMS

Attenuation storage tank systems can generally be used for any site requiring subsurface storage of surface water runoff, provided that the system is demonstrated to function satisfactorily both in terms of hydraulic capacity and structural performance.

Effective upstream treatment is an important consideration to control the risk of the system performance being compromised by sediment build-up. This is particularly important for geocellular and arch systems where access and sediment removal opportunities tend to be constrained. To limit the likelihood of sediment accumulation, it is recommended that the area drained to the tank should be as small as practical for any given site: thus the use of several smaller tanks is preferable to a single larger system.

It is recommended that attenuation tanks are installed above the groundwater table, because groundwater pressure significantly increases lateral loads on the walls of the tank, and even a small defect in the surrounding waterproof geomembrane or pipe joints can result in groundwater entering the tank and filling the design storage volume. Where a storage tank has to be installed either close to or below the groundwater table, the possibility of floatation should be prevented by ensuring that the combined weight of the tank and the soil over the top is greater than the uplift buoyancy force due to the groundwater (with an appropriate safety factor (**Section 21.4.1** – Step 3). Alternatively, specialist geotechnical advice should be sought on possible anchor systems.

In areas containing contaminated soils or contaminated groundwater, an appropriate risk assessment should first be undertaken and the results used to specify appropriate materials for the tank, any geomembrane surround (**Chapter 30**) and joint sealant. Any excavation or earthmoving processes required should be assessed to ensure that mobilisation of contamination does not occur.

21.3 GENERAL DESIGN CONSIDERATIONS

Consultants who are responsible for the design of drainage often allow the structural design of all types of tanks to be carried out by manufacturers. This can lead to confusion about who is legally responsible for the design in situations where failures have occurred, as manufacturers had only provided design suggestions and were not employed under contract to provide design services. It is therefore vital that it is legally clear who is contractually responsible for both the structural and hydraulic design of a system. If a manufacturer is to undertake the design then they should be employed under a contract to specifically provide the design services. The design and communication responsibilities between the appointed parties – client, designer, contractor and unit manufacturer – can be clearly defined via the CDM process: Construction (Design and Management) Regulations (CDM) 2015.

It is preferable that the organisation that is responsible for the hydraulic design of a tank is also responsible for the structural design, to avoid any confusion in responsibility.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

21.4 STRUCTURAL DESIGN

Each different type of tank system will have its own specific design guidance and British, European or American Society of Testing and Materials (ASTM) Standards, based on the structural form and types of materials they are manufactured from. The relevant standards, codes of practice and guidance should always be followed.

The following factors require careful consideration for all systems, to ensure a robust and adequate design. These are adapted from O'Brien *et al* (in press):

- appropriate structural, geotechnical and hydraulic design methods and the information required by those methods
- the influence of specific site ground conditions on the structural and hydraulic performance of the tank
- the influence of the tank on the surrounding ground
- the importance of long-term unit deformation processes (creep) for the design of plastic tanks
- the applicability and relevance of manufacturers' laboratory strength testing results
- manufacturers' design limitations on system performance, eg depth constraints
- the predicted structural performance of the tank and any scenarios that might lead to overloading, such as the running of heavy plant across tanks not designed to carry such loads, or the use of unsuitable backfill, for example containing boulders or soft clay
- the influence of groundwater levels on system structural and hydraulic performance
- the influence of infiltration of water on the surrounding ground and external tank loadings; for example, there have been cases where water seepage out of deeper unlined geocellular tanks has caused a rise in pore pressures in backfill or soils around the tank, which has increased the earth pressure on the side of the tank, leading to structural failure; the risk of infiltration water reducing the strength of soils below any nearby foundations also requires careful consideration
- the effect of surface water flows into excavations during construction, which could cause flotation of tanks during construction
- the risk of detailing errors and late on-site changes by contractors, such as increasing the depth, changing overlying pavement layers, spanning tanks over channels or changing the type of tank.

From a structural perspective, tanks may fail to perform adequately if either the basic structural frame is overstressed or it moves excessively, or for some systems if the outer skin is torn or moves excessively. It is important for the designer to understand the fundamental aspects of tank behaviour, based on an appreciation of its structural form and material composition. This will then enable the designer to interpret the test data available for the tank system, and to select an appropriate type of tank, given the specific site conditions and loading regime.

Calculations should be carried out to check that the tank will be stable and will not move excessively under the anticipated range of loading conditions during the design life of the tank installation. As a minimum, three separate checks need to be made. These are to determine that:

1. the structure is stable under normal working loads for the permanent works
2. the structure is stable under accidental loads – the ability of the units to withstand occasional extreme loads should be checked, for example HGV or maintenance vehicles moving across a car park, or large mowing vehicles for shallow installations within landscaped areas
3. the structure is stable during the site works – loads to be applied during construction need to be known, or appropriate assumptions made, together with their location relative to the tank; these assumptions should be stated on the project drawings.

The design strength should be compared to the design loads for the scenarios described above. The design strength should be greater than the design load. Also, on most sites there will also be a requirement to carry out a serviceability check to make sure that horizontal and vertical deflections are not excessive and will not adversely impact overlying surfacing materials or nearby structures. The design loads are also used to estimate deflection or settlement using the design deflection properties of the tank.

For any type of system, claims by manufacturers regarding performance should ideally be supported by independent verification (eg British Board of Agrément [BBA] certification).

Typical loads that should be considered for any tank are shown in **Figure 21.16**.

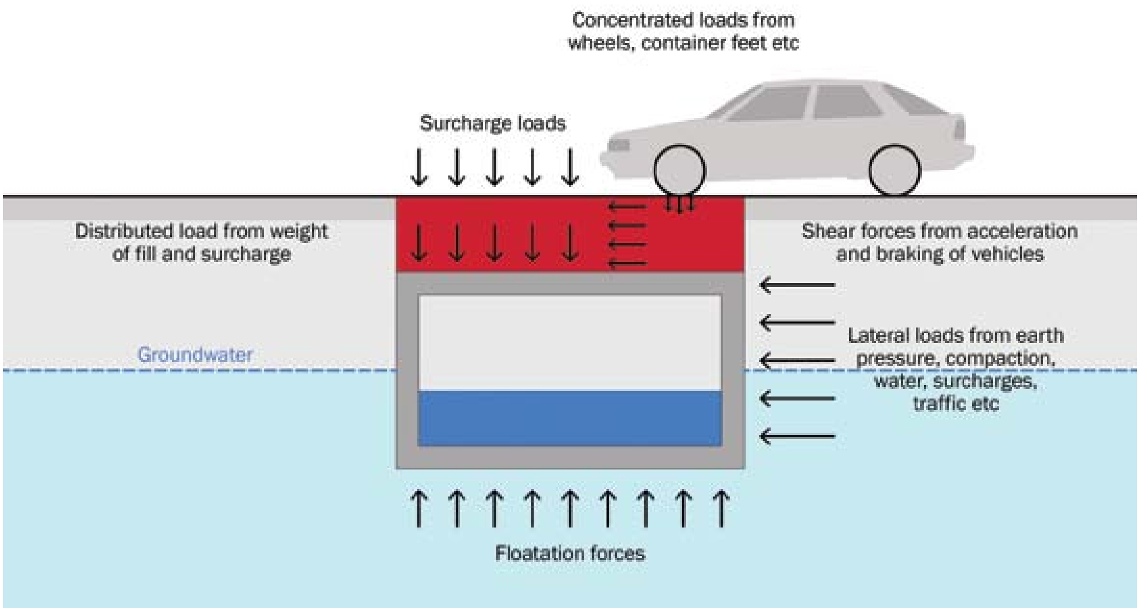

Figure 21.16 Typical loads to be considered in structural design of attenuation tanks

The main loads to be considered are:

- weight of soil on top of the tank
- characteristic traffic loads (point loads from vehicle wheels and general surcharge load)
- earth/groundwater pressures (which are based on the ground model for the site)
- loading from maintenance activities to any nearby buildings/landscape (eg cherry pickers)

- accidental loads that could reasonably be anticipated (eg an HGV movement on a residential car parking zone)
- loads from temporary works during construction (eg cranes).

The weight of the soil should be determined using a conservative value of bulk density.

The flowchart in **Figure 21.17** (and the steps described below) has been developed specifically for the design of geocellular tanks. However, the general principles are applicable to the structural design of any buried structure that stores surface water, and so the flowchart can be used as a guide to the design of all the other types of storage tank described in **Section 21.1**.

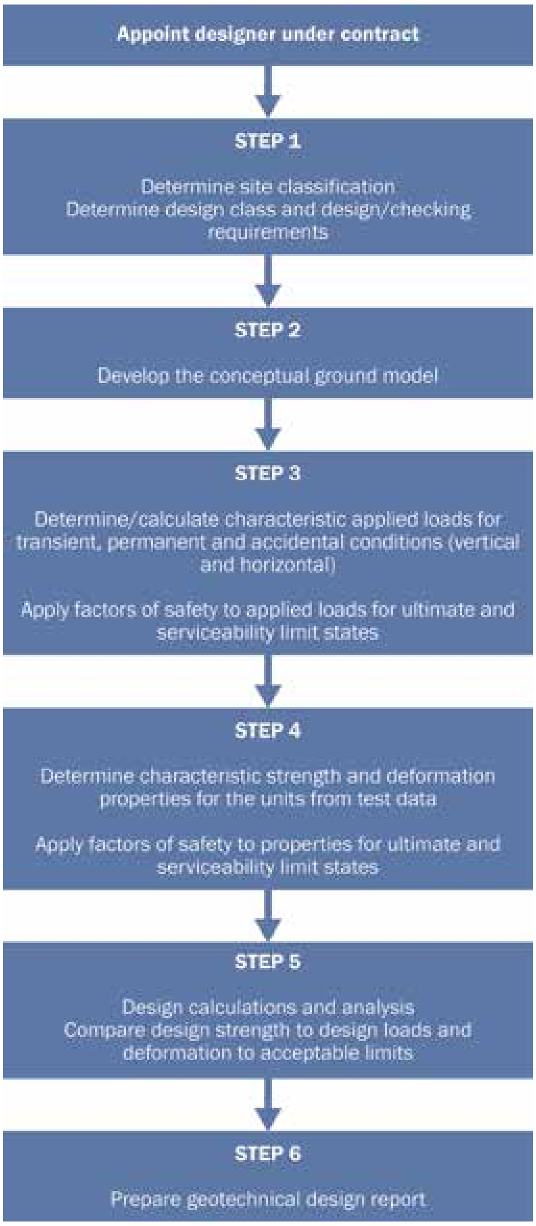

Figure 21.17 Simplified summary of structural design process for geocellular units

214.4.1 Geocellular storage systems

The structural design for the main types of geocellular systems used in the UK should be in accordance with O'Brien *et al* (in press). This is consistent with geotechnical Eurocodes and covers all types of geocellular units. This report should be read in full before the appointed designer attempts the structural design of geocellular units.

A simplified flowchart that describes the key steps in the structural design of geocellular tanks in accordance with O'Brien *et al* (in press) is provided in **Figure 21.17**. The steps are described in more detail in the following sections.

Step 1 – Determine site classification

The first step in the structural design is to determine the site classification. The classification gives an indication of the level of risk associated with the tank and therefore determines the level of professional qualifications required of the designer, the extent of design information required of the units or ground properties, the complexity of calculations and analysis and the level of checking required. The more complex the circumstances or the more severe the consequences of failure, the greater the extent and detail of the calculations that are necessary for the design. O'Brien *et al* (in press) provides more detailed information on the scoring system. The site classification system covers the range from 0 (very low risk) to 3 (high risk). The design checks and professional experience of the checker can range from relying on supplier advice for very low risk applications up to the need for an independent Category 3 check of the design for high risk schemes (eg in the hard shoulder of a motorway where the units are within the influence of a structure). Details are provided in **Table 21.1** which is from O'Brien *et al* (in press).

Note that some local highway authorities may classify anything as a highway structure if it is within 3.66 m of the highway or it has an internal span or diameter greater than 900 mm (including pipes with a diameter or aggregate diameter of multiple smaller pipes greater than 900 mm to manholes or inspection chambers). The highway authority should be consulted on whether tanks close to the highway are to be regarded as Category 3 in **Table 21.1**.

TABLE 21.1 Classification and recommended calculations for geocellular systems

Site classification	Criteria	Examples	Design information required	Calculations and analysis required	Qualifications of designer
0	Consequence of failure/excessive deformation, in context of safety, are minor. Size of installation is small (less than 3 m^2), project below notification requirements for CDM 2015.	Domestic applications such as a soakaway for a single house.	Services search or cat scan for services.	No formal design calculations required. Unit supplier to advise on application suitability of unit.	Unit supplier installation advice usually sufficient
1	Consequence of failure/excessive deformation, in context of safety, are minor; units will be installed in competent ground, eg firm to stiff clays or medium to dense sands (or stiffer/stronger ground), site is predominantly flat, and units are remote[2], from foundations, slopes, retaining walls.	Located in agricultural land or remote landscaping. Located beneath private access roads, occasional use less than 15 mph. Located beneath or adjacent to car parks, with no HGV traffic (ie height/width barriers in place).	Desk study. Intrusive ground investigation to verify geology and site history. Standardised manufacturer information and testing, based on design life and creep rupture testing for unit capacity likely to be sufficient.	Undertake calculations for vertical distributed and concentrated loading. Check adequacy of cover to units for attenuation of concentrated loading (simple load spread angle) and with respect to groundwater (flotation check). Assess “active” pressures (K_a) for lateral load on installation.	Incorporated or chartered engineer

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TABLE 21.1 Classification and recommended calculations for geocellular systems

2	Consequences of failure, in context of safety are minor. Large deformation may adversely affect functionality of facility, or units located shallower than 1 m, deeper than 3 m or located in soft clays or loose sands or located in vicinity[1] of foundations, slopes, retaining walls.	As for Class 1, but soil–structure interaction is potentially more complex. Site functionality affected by deformation in excess of 50 mm^3 or differential movements in excess of 1 in 200. Located beneath public roads, subject to low to moderate speed (less than 30 mph) traffic. Parking areas accessible to HGVs.	As Class 1, plus site-specific quantitative data to verify ground strength and deformation characteristics. As Class 1, plus creep test data for geocellular units to assess long-term deformation. Greater understanding of the performance and manufacturer testing undertaken of the units required. The likely loading, fatigue, creep and temperature of operation may lead to specific testing or further investigation of unit performance.	Sloping ground will require considered assessment of lateral loading. Recommended to include slope stability calculations, assessment of pre-existing shear zones in slopes. Note: lateral pressures can be significantly higher than K_a (for horizontal ground). Detailed assessment of the installation regarding construction activities, such as stockpiles, plant or crane operations. Detailed assessment of adjacent structures, such as load paths of foundations.	Chartered civil engineer, with more than five years' post chartered experience
3	Consequences of failure, in context of safety, are severe. Functionality of facility or adjacent pavements/structures sensitive to small deformations. Units located shallower than 0.5 m, or deeper than 4 m. Located in ground which is potentially unstable.	Located beneath or adjacent to specialist loading facilities (cranes etc). Located beneath or adjacent to public roads subject to high speed (more than 30 mph) traffic. Subjected to significant cyclic loads. Site functionality affected by deformations less than 50 mm^3 or differential movements of less than 1 in 200. Regularly exposed to liquids at high temperatures.	As Class 2, but may also need specialist sampling or tests to more reliably measure ground deformation characteristics. As Class 2, plus possibly specialist test data for tank, or measurements of strength and stiffness at high (> 25°C) temperature.	Bespoke analysis required, supervised by senior specialist geotechnical engineer of geotechnical advisor status.	Geotechnical advisor (see SISG, 2012)

Notes

1 A higher design classification may be used in order to justify a more economical design; for example, a more rigorous analysis of soil structure interaction may lead to increased confidence in the performance of a tank, and allow lower quality backfill to be used around the tank or avoid the need for additional measures to reduce the earth pressure on the side of the tanks.

2 See O'Brien *et al* (in press) for definitions of "remote from foundations, retaining walls, slopes etc."

3 The design check requirements are intended as a minimum guide for consideration and are not an all-encompassing exhaustive list. Further requirements and checks may be required depending on the particular circumstance and as directed by a competent designer.

Step 2 – Develop the conceptual ground model

Many construction cost overruns are caused by unforeseen ground or groundwater conditions, and collapses of structures including geocellular tanks have occurred because of a lack of understanding of the ground or groundwater. The development of a conceptual ground model is an important step in ensuring the successful design, construction and operation of geocellular tanks.

The conceptual ground model shows the possible subsurface conditions that can be predicted from the available desk study and ground investigation data for a site (Geological Society, 2002). Developing a ground model that includes the known and suspected features below and adjacent to a site will help identify the likely implications of the ground for the design of a tank and ensure that appropriate analyses are completed.

It is often useful to draw the conceptual ground model as a three-dimensional diagram that allows the scale and location of ground features to be assessed in relation to the tank. The model should include a characterisation of the geology in engineering terms, which will allow the geotechnical properties and their likely lateral and vertical variation to be assessed within the context of the model.

Key information that should feed into the ground model includes:

- overall site topography and potentially adverse effects of nearby structures/earthworks (eg increased earth pressure at the foot of an embankment), and/or vegetation (eg retaining walls, slopes, temporary, permanent or future planned works or changes in moisture content and swelling or shrinkage of soil due to trees)
- site history and geology (eg ground/groundwater contamination, historic landslips or mining)
- groundwater levels and flows
- the soil-structure interaction between the tank and the surrounding ground.

Step 3 – Design loads and partial factors of safety

The next step in the design is to determine the applied loads from all sources (horizontal and vertical).

Characteristic loads are a best estimate of the load likely to be placed on a structure during its design life. The characteristic loads derived for the permanent and temporary works need to be factored to allow for possible variations and dynamic effects, in order to calculate the design loads, and guidance is again provided in O'Brien *et al* (in press). Advice on loads in areas such as ports, where very heavy machinery is present is provided by Interpave (2010). It is normal to apply dynamic factors to container loading equipment for pavement design in these areas, and it would be prudent to do so for geocellular tanks.

The horizontal loads (or actions) will depend on the properties of the surrounding soils. When assessing the ground properties used to calculate earth pressures, the advice of a geotechnical engineer or engineering geologist should be sought. The presence of groundwater at the site needs to be investigated, both at the desk study stage and during the ground investigation, and given careful consideration when interpreting likely future site conditions over the tank's design life. When geotechnical problems occur, it is often due to unforeseen groundwater problems. It is particularly important to consider the potential for seasonal and weather-related fluctuations in the groundwater regime.

Standard soil mechanics theory as described in many textbooks is used to determine the applied horizontal loads (eg Barnes, 2010). The characteristic properties of the soil should be determined from site investigation data, and these are reduced by the appropriate partial factors provided in O'Brien *et al* (in press) and also site importance factors which are intended to ensure that the probability of failure is sufficiently remote, depending upon the site classification and associated consequences of failure.

Step 4 – Determine design strength and deformation properties for the system

The structural properties for the system to be used will be required to allow the design to be completed. This information should be provided by the supplier or manufacturer of the system being considered and should have been derived via certified testing programmes. The test data and certificates for the units are normally required by the designer.

The type of tests vary from quick compression tests to long-term creep rupture tests, using both full load platens (cover the entire surface of the box) and 300 mm diameter load platens. The test data required for installations depends on the site classification – the higher the site classification the greater the extent of test data that is needed.

The results from laboratory tests are used to arrive at a characteristic strength. The characteristic strength is reduced by partial factors of safety to determine a design strength for the units. This process is explained in O'Brien *et al* (in press). The test methods should replicate the behaviour of the structure when it is in the ground.

Many manufacturers only supply test data for single units. Some types of units may behave differently when stacked on top of each other, depending on the layout of the units within the tank and the nature of the applied loading: the strength can reduce, or deformations may increase. This aspect needs careful consideration by the designer, and, as recommended by O'Brien *et al* (in press) may necessitate full-scale *in situ* testing.

Risk of damage to overlying pavement surfaces is a function of elastic short-term differential movement, not total movement. However, the use of allowable total movement criteria under repeated traffic loads is helpful, for routine simple assessments, and as a trigger for indicating the need for more detailed analysis. The allowable movement criteria need to be realistically assessed, based on the specific use of a site, its functionality and the nature of the paving system.

Step 5 – Design calculations and analysis

Once the design loads and design strength/deformation properties have been determined then the designer will need to undertake checks on the following modes of failure for each scenario when designing geocellular unit installations:

1. **Global stability and deformation** – This is a check on the overall stability of the tank and surrounding ground. It is essential that the overall stability and deformation of the site is checked. These checks should be summarised in the geotechnical design report, and will include issues such as checks on the stability of any slopes or retaining walls located on or adjacent to the site, and a review of any potential geohazards or historical activities (eg solution features in chalk, mining or quarrying activities), which may lead to global stability or subsidence risks. Global deformations may develop because of swelling in the base of excavations, settlement over non-engineered fill material or soft, compressible soils, the presence of metastable soils, volume changes in clay soils due to the presence of trees. Global movements need to be carefully assessed by an appropriately experienced geotechnical engineer.
2. **Interaction checks** – It is essential that the units are designed, taking into account any interactions (either extra loading on the tank or potential instability due to the tank) with existing structures, existing slopes, building foundations, retaining walls, adjacent highways/railways or any similar structures or features. It will often be desirable to relocate the location of the geocellular unit where possible to minimise the interactions with adjacent structures rather than having to design to account for them.
3. **Stability of geocellular unit** – The stability of the geocellular units should be assessed under the applied loads. This is an ultimate limit state. This should include a check that the design vertical and horizontal strength of the geocellular units is greater than the design vertical and horizontal loads respectively (both in the short term for temporary works and in the long term). It should also include, where appropriate, the overall stability of the geocellular units in terms of overturning or shearing of the units themselves. Flotation should be considered for tanks below the groundwater table or if groundwater level could rise over the design life of the tank.
4. **Deformation of geocellular unit** – Considering the deformation is a serviceability check. Lower factors of safety than those used for ultimate limit state assessment are applied to loads, soil properties and the unit properties for a serviceability check. The magnitude of the allowable

settlement (or horizontal movement) of geocellular units will often be critical to design, due to the long-term creep behaviour of plastics. It is important that the geocellular unit designer is involved in discussions with the overall project designer, before an allowable movement is decided. Both long-term deformation due to creep and short-term elastic deformation should be checked. As discussed in O'Brien *et al* (in press), if units are exposed to significant traffic loading, then specialist cyclic testing may be required to assess their behaviour under repeated loading. The assessment of short- and long-term movements will be particularly important if sensitive services or structures are located in the vicinity of a tank.

Step 6 – Prepare geotechnical design report

The geotechnical design report is an important document, referred to in BS EN 1997-1:2004+A1:2013, which allows those constructing the tanks and managing them during operation to understand the assumptions and limitations within the design (eg assumptions about construction methods or loads). The report summarises the ground model, data, methods of calculation and results of calculations. It will also identify the level of supervision, testing or monitoring and maintenance required during construction or operation. The detail required in the report will depend on the complexity of the project. For simple designs, a single page may be sufficient, whereas complex designs may require a comprehensive report (Frank *et al*, 2004). A checklist of items to be provided in the geotechnical design report is provided in BS EN 1997-1:2004+A1:2013.

The geotechnical design report should be updated if any changes are made to the design as construction progresses, and it should form part of the records for the project that are included in the health and safety file (provided to the client at the end of the project, as required by CDM 2015).

▶ Further information on the contents of the geotechnical design report is provided in BS EN 1997-1:2004+A1:2013.

21.4.2 Plastic corrugated arch structures

Many of the general requirements for the structural design of geocellular tanks also apply to plastic arch systems. There are two ASTM standards that provide guidance on the required structural properties and load testing of plastic arch systems (one for those manufactured from polypropylene and the other for those manufactured from polyethylene):

- corrugated arch chambers manufactured from polypropylene – ASTM F2418-13 – the design of these systems are not covered in detail in this manual
- corrugated arch chambers manufactured from polyethylene – ASTM F2922-13e1

The site classification system described in Step 1 of the structural design for geocellular units may also be applied to plastic arch systems, to ensure that the design is carried out and approved by someone with appropriate qualifications and experience. The development of a conceptual ground model as described in Step 2 for geocellular systems is also important, as is the geotechnical design report described in Step 6.

Guidance on the structural design of any type of plastic arch system is provided in ASTM F2787-13. The structural design includes the design of the composite system made up of the chamber arch, the chamber foot and the soil envelope. Important factors that should be addressed in the design are:

1. creep deformations over time and the creep rupture strength of the arches
2. global and local buckling of the arch walls, tensile stress in walls, capacity of the foundation material to support bearing pressure from the chamber foot and the capacity of the subgrade to support the loads from the foot
3. influence of adjacent arches on each other
4. the displacements that will occur under load and the effects that these may have on the surfacing above, the hydraulic performance and the distribution of loads assumed in the model for item 2 above

5 test results from full-scale testing of completed installations (this does not require testing of every installation) to support the chamber design calculations.

Where appropriate, the load requirements stated in ASTM F2787-13 should be replaced by those in the relevant Eurocodes. The design of plastic arch systems should also comply with relevant requirements of geotechnical Eurocodes.

21.4.3 Oversize concrete pipes

The structural design of concrete pipes should follow the guidance provided in BS EN 1295-1:1997 using the national design method in Annex A. Guidance on how to apply BS EN 1295 to concrete pipe design is provided by CPSA (2013). Guidance is also provided in BS 9295:2010. A summary of the national design methods is provided in PD CEN/TR 1295-2:2005.

Concrete pipes should meet the requirements of BS EN 1916:2002 and BS 5911-1:2002+A2:2010. The standards place pipes into different strength classes based on their maximum crushing load, although most standard pipes available in the UK meet the requirements for Class 120. The pipes should not collapse under the maximum load specified when tested in accordance with the standards. Proof load tests are also required, and reinforced pipes should not crack by specified amounts in this test (the proof load test for unreinforced pipes is the maximum load).

Small diameter pipes up to 300 mm diameter can also fail due to longitudinal bending (ie as a beam), and the standards also specify minimum values of bending resistance for pipes.

Concrete pipes are rigid and have a high inherent strength. They resist applied loading by a bending action within the pipe walls. They are generally stiffer than the pipe surround material, in particular the side fill, and therefore support a higher load than the side fill material. The structural design described in BS EN 1295-1:1997 considers the loads applied to the pipes (including the influence of the trench walls and backfill) and the influence of the pipe bedding and surround on the applied loads. A factor of safety between 1.25 and 1.5 is used in the design (this is the global factor of safety).

One of the main considerations in the design of any pipe structure is the location in which the pipe is installed. These construction conditions are categorised as:

- narrow trench
- wide trench or "on the surface", over which an embankment is then built
- narrow trench over which an embankment is then built
- tunnel, heading or when the pipe is to be installed by jacking.

The installation location has a significant influence on the loads that the pipe will have to support. Therefore, any assumptions made in the design should be made clear on drawings by the designer so that construction of the tank does not invalidate them. The narrow trench condition will give suitable working space around the side of the pipe during installation. If the trench width is increased significantly beyond this, there comes a point where the friction between the backfill and trench walls no longer contributes to load reduction on the pipe and consequently loads on the pipe increase.

For pipes above 600 mm diameter, some part of the water load under working loads should be allowed for in the structural design. Often the pipes may well be subject to the highest loads during construction and this should be taken account of in the design.

Rigid pipes will to some extent rely on the backfill structure to transfer loads into the bedding and any assumptions made in the design regarding these aspects should be clearly stated on any design drawings.

The general principles of the site classification system described in Step 1 of the structural design for geocellular units may also be applied to oversize concrete pipe systems with some modification to ensure that the design is carried out and approved by someone with appropriate qualifications and experience.

The development of a conceptual ground model as described in Step 2 for geocellular systems is also important, as is the geotechnical design report described in Step 6.

21.4.4 Oversize plastic pipes

The structural design of plastic pipes should follow the guidance provided in BS EN 1295-1:1997 using the national design method in Annexe A. Guidance on how to apply BS EN 1295-1 to plastic pipe design is provided in BS 9295:2010. Various manufacturers also provide their own guidance on how to apply the British Standard.

Plastic pipes are flexible, and deform under load to form a slightly oval shape in the ground. The deformation is an important part of developing the load capacity of the pipe/soil system. As the pipe moves outwards horizontally the passive earth pressure increases until the pipe–soil system comes into equilibrium.

Further deformation will not occur thereafter unless a higher vertical load is applied to the pipe–soil system or consolidation (or creep) of the materials occurs over a long period of time. It is internationally recognised that when a pipe is installed in accordance with an appropriate code of practice, increases in deflection virtually stop after a short period of time. The duration of time is dependent on soil and installation conditions but generally does not exceed two years.

The performance of the pipe will depend on:

- stiffness of the natural soil in which the trench is cut (represented by soil modulus)
- density of the overburden
- magnitude of dynamic loads due to trafficking
- hydrostatic loading
- acceptable factor of safety against buckling (typically >2 with soil support and >1.5 without soil support)
- stiffness of the pipe bed and surround and the elastic modulus of the surrounding soil
- specified maximum limit of deflection.

Soil modulus has a significant effect on the results and should be carefully assessed. Where the soil surrounding the trench walls is a weak material, the level of support provided will be much lower than any specified pipe surround. Therefore, only considering the modulus of the pipe bed and surround will over-estimate the overall modulus of the pipe/soil system.

As with other plastic systems, creep is an important consideration, and all pipe manufacturers will provide the results of creep tests for use in the design.

A limit on vertical deformation is necessary to ensure adequate long-term performance of plastic pipes. Appropriate deflection (serviceability) limits should be set on a case-by-case basis. For example, greater limits may be allowable in a deep landfill installation compared to a pipe buried at a shallow depth under a road. Deflection limits within the UK vary, depending on the relevant adopting authority. For design purposes DfT (2001) specifies a maximum allowable deformation of 5% for thermoplastic structured walled pipes, while the water industry tends to specify 6% based on the requirements of BS EN 1295-1:1997.

Flexible pipes rely on the backfill structure to help support loads, and any assumptions made in the design regarding these aspects should be clearly stated on any design drawings.

The general principles of the site classification system described in Step 1 of the structural design for geocellular units may also be applied to oversize plastic pipe systems, with some modification to ensure that the design is carried out and approved by someone with appropriate qualifications and experience. The development of a conceptual ground model as described in Step 2 for geocellular systems is also important, as is the geotechnical design report described in Step 6.

21.4.5 Corrugated steel pipes

Corrugated steel pipes are considered to be flexible and are designed following BS 1295-1:1997 and the associated guidance documents. Advice is also provided in HA (1991). This is routinely used as a design tool by some manufacturers. Specific advice is also provided by manufacturers of these systems.

In terms of structural design, the issues raised in relation to plastic pipes apply to these systems as well, although the magnitude of creep deformation in steel structures is far less than in plastic. The design does however need to take account of the protection provided against corrosion and make a suitable allowance for corrosion and loss of section over the design life.

As per oversize plastic pipes, flexible corrugated steel pipes rely on the backfill structure to help support loads, and any assumptions made in the design regarding these aspects should be clearly stated on any design drawings.

The general principles of the site classification system described in Step 1 of the structural design for geocellular units may also be applied to corrugated steel systems with some modification to ensure that the design is carried out and approved by someone with appropriate qualifications and experience. The development of a conceptual ground model as described in Step 2 for geocellular systems is also important, as is the geotechnical design report described in Step 6.

21.4.6 Precast concrete box culvert sections (including flat-packed concrete panels)

Precast box culverts should be treated as a structure and the structural design should be undertaken by a suitably qualified structural engineer. The design should comply with the relevant Eurocodes for precast reinforced concrete and BS EN 14844:2006+A2:2011. Further advice is provided by the BCA (2014).

21.4.7 Glass-reinforced plastic (GRP) tanks

Circular GRP pipes are considered to be flexible pipes in accordance with BS EN 1295-1:1997. Structural design should follow the design guidance in that document, as explained above for plastic and steel flexible pipes.

As per all other types of flexible pipe, these pipes rely on the backfill structure to help support loads, and any assumptions made in the design regarding these aspects should be clearly stated on any design drawings.

21.4.8 Hybrid tanks using reinforced earth walls and concrete roof panels

Hybrid tanks have two elements:

- precast concrete roof panels – designed by a structural engineer to comply with the relevant Eurocodes for precast reinforced concrete described above for box culverts
- reinforced soil abutments – designed in accordance with BS 8006-1:2010. The design should also follow other relevant geotechnical Eurocodes – advice is also provided in HA (1996a)

The general principles of the site classification system described in Step 1 of the structural design for geocellular units may also be applied to hybrid systems to ensure that the design is carried out and approved by someone with appropriate qualifications and experience. The development of a conceptual ground model as described in Step 2 for geocellular systems is also important, as is the geotechnical design report described in Step 6.

21.5 HYDRAULIC DESIGN

21.5.1 General

The hydraulic design of on- or off-line storage systems using pipes or tanks should be in accordance with WRc (2007, 2010 and 2012) using standard routing methods (**Section 24.11**). Useful information is also provided in BS EN 752:2008.

Infiltration systems should be designed to comply with **Chapter 13** and other current guidelines (BRE, 1991, or Bettess (1996).

The velocity of water entering tanks from larger pipes can be significant, and the internal structure can provide sufficient resistance to cause water to back up in the pipework. This is mainly a problem for geocellular systems. In order to minimise this effect, most manufacturers of geocellular systems recommend the use of manifolds to split the flow into a series of smaller pipes that are connected into the tank (**Figure 21.18**).

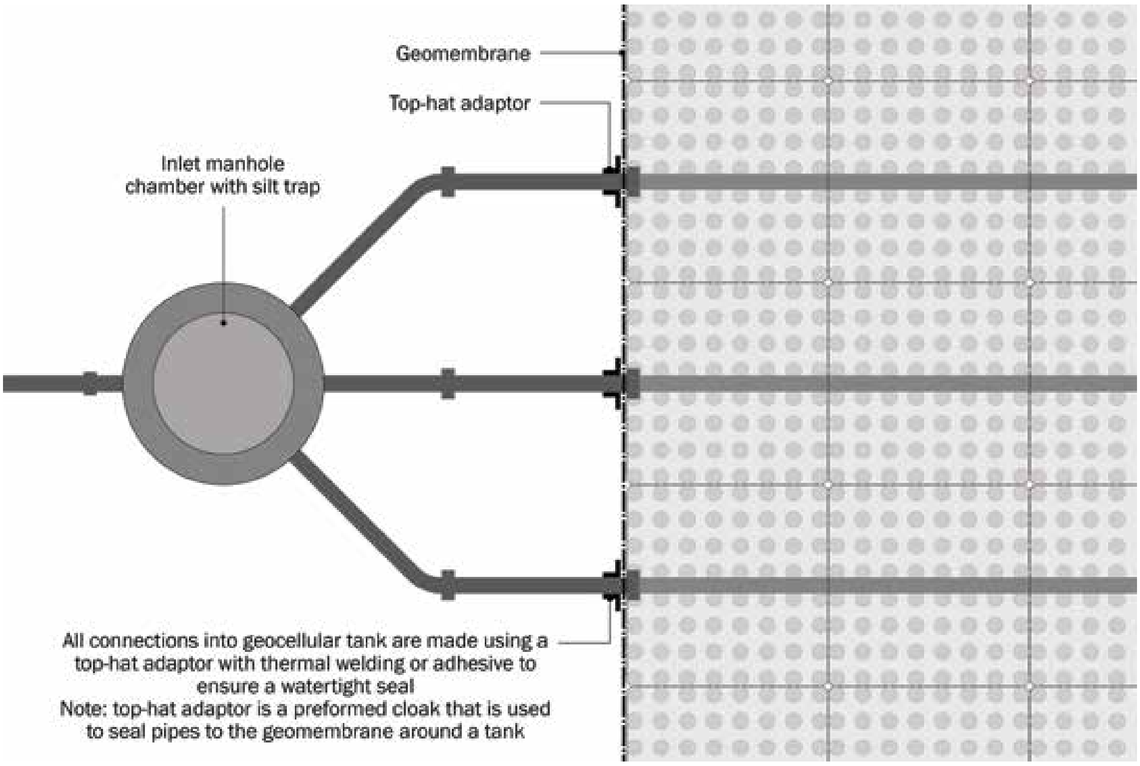

Figure 21.18 Manifold to distribute flows from large pipe into geocellular tank

Particular care is required where syphonic roof drainage discharges into any type of tank that the inlet is adequate to cope with the flows. It is usual to provide a brake chamber to slow down flows. It is also vital that sufficient venting of the tank is provided where syphonic roof drainage enters tanks, to prevent uplift pressures rupturing the overlying surface during rainfall events.

21.5.2 Interception design

Tanks that are designed as attenuation systems and are fully impermeable do not provide any Interception, because all runoff will flow through and be discharged from the tank. Appropriately designed attenuation tanks (ie only draining small catchment areas) that are not lined and allow some water to leak into the surrounding soil can provide Interception if the soil has sufficient capacity for infiltration (usually this can be achieved in soils with permeability as low as 1×10^{-8} m/s). This does, however, require careful design, and shallow tanks taking runoff from relatively small areas are preferred.

There have been cases where water seepage out of deeper unlined tanks has caused a rise in pore pressures in fine sands around the tank, and this has increased the earth pressure on the side of the tank, leading to structural failure. There is also a risk of reducing the strength of soils below any nearby foundations. Therefore, a thorough geotechnical assessment of the impact of water seeping from larger and deeper tanks may be necessary.

21.5.3 Peak flow control design

Attenuation tanks can help reduce flow rates from a site by providing attenuation storage. The available storage volume is provided by the void space in the tank structure:

Available attenuation storage in the tank = Volume of tank × tank porosity

The size of the tank should be determined using the hydraulic design methods described in **Section 24.9**. A flow control structure is generally required to constrain the rate of water discharged from the tank. Often underground tanks are designed to attenuate rainfall events up to 1:30 year event greater than this are stored above ground.

If the head–discharge relationships from hydraulic flume tests are known for geocellular units they can be also be used to convey water across a site and can in some circumstances provide the necessary discharge control, removing the need for other flow controls such as orifice plates or vortex flow controls.

It is common practice to oversize the design volume of any tank that is considered to be at risk of sedimentation and hard to maintain by 10% to allow for loss of storage due to sediment build-up. This is a precautionary measure and is not a replacement for effective sediment management upstream of the tank. The 10% figure is an arbitrary value and may be inappropriately large in some applications. For example, a system taking only roof runoff would take 250 years to suffer a 10% loss of storage volume. **Table 21.2** provides more information.

21.5.4 Volume control design

Contribution of storage tank systems to volume control should be evaluated using standard methods – based on expected infiltration rates and/or available attenuation storage and specified flow controls (**Section 24.10**).

21.5.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the tank system. This can be achieved by installing an overflow pipe above the design water storage level in the tank or overland flow routing from surcharging components upstream of the system (**Section 24.12**).

21.6 TREATMENT DESIGN

Storage tank systems do not provide any form of treatment of surface water runoff, and they therefore need to be combined in a Management Train with other methods that do provide suitable treatment of all relevant pollutants (**Chapter 26**). Treatment to remove coarse sediment should always be provided upstream of a tank.

21.7 AMENITY DESIGN

Storage tank systems can provide amenity value if they are storing water for use. They can also promote the multi-functional use of space, by allowing the surface above the tank to be used for recreation or other amenity facilities. Tanks can also be used in conjunction with other surface features so that water level rises in those features can be minimised to maximise their amenity value and minimise health and safety risks.

21.8 BIODIVERSITY DESIGN

Storage tank systems do not have any inherent biodiversity value, but they can help reduce the impact of heavy flows on the downstream system, and this can help facilitate biodiversity delivery in those areas.

21.9 PHYSICAL SPECIFICATIONS

Attenuation tank structures are commonly used components of drainage systems. The specification of the system should be based on its required performance at a particular site, as determined from the hydraulic and structural design calculations and models discussed earlier in this chapter.

There are many standard specifications available (eg WRc, 2012, and DfT, 1998) that may be used for these types of structure. British Board of Agrément (BBA) or other certification can provide some of the information necessary for design approval but they should be read carefully to understand the limitations imposed by the certificate (**Box 21.1**).

BOX 21.1 The use of BBA and other certification schemes

BBA certificates, CE marking and other certification schemes are only intended to help designers, procurement professionals and regulators understand the potential performance of a product (DECC, 2012). For example, the performance of a product can be stated in terms of strength, deflection under load and creep deformations over specified design lives.

Certification establishes the technical performance of a product (or a "system", if the performance depends on the provision of different components) for specified loading conditions. The required performance on a particular site depends on where it is going to be used (depth, lateral pressure, traffic loads etc). The designer of the drainage system will need to assess whether the level of performance stated in the certificate satisfies the loading and allowable deflection conditions that apply to the project in question (DECC, 2012). A certificate is not a guarantee that a particular product is appropriate in any defined situation. Design calculations are still required and should be checked rigorously. The certificate should be read carefully, especially with regard to design life and limitations on the applications covered by the certificate.

It is often erroneously believed that BBA certification of products is required to comply with Building Regulations or to gain building control approval. This is not the case (DECC, 2012).

21.9.1 Geocellular structures

There are currently no British or European standards for geocellular structures or units, although there is work being done at the time of going to press to develop European product and testing standards.

Specification of geocellular or modular structures will comprise three parts:

- specification of the structural unit
- specification of the wrapping material (geotextile and/or geomembrane) – see **Chapter 30**
- specification of the backfill material – see **Section 21.10**

The following properties should be specified for geocellular units and backfill, so that designers can evaluate their suitability for a specific design application:

1. material used in manufacture (including any recycled material)
2. hydraulic properties (including head–discharge relationships if to be used for conveyance)
3. vertical and horizontal long-term strength over a specified operational time (note that long-term strength is not only a function of elapsed time, it is also a function of the applied load; a unit loaded with 20 kN/m^2 will have a higher strength at 50 years than the same unit loaded with 70 kN/m^2
4. vertical and horizontal strength at specified temperature (if appropriate, eg in hot climates)
5. impact strength if appropriate (eg in cold climates)
6. vertical elastic deflection under short-term traffic loads and under long-term loads

7 horizontal deflection under short-term and long-term loads

8 fatigue resistance to cyclic loading (where cover is less than 1 m and significant HGV traffic is expected)

9 response to traffic loads and pavement design parameters from full-scale trials, such as Benkelman beam and falling weight deflectometer tests (these road pavement surface tests have been used to test the performance of sub-base replacement systems)

10 type of backfill and any requirements for compaction plant

11 acceptable test methods or test standards for the above – see O'Brien *et al* (in press)

21.9.2 Plastic arches

There are two ASTM standards that provide guidance on the specification of the properties of plastic arch systems (one for polypropylene and the other for polyethylene):

- corrugated arch chambers manufactured from polypropylene – ASTM F2418-13; the design of these systems is not covered in detail in this manual
- corrugated arch chambers manufactured from polyethylene – ASTM F2922-13e1

The chambers are produced in arch shapes and classifications specify chamber rise, chamber span, minimum foot width, minimum wall thickness and minimum arch stiffness constant. Chambers are manufactured with integral footings.

21.9.3 Oversize concrete pipes

Concrete pipes should meet the relevant requirements of BS EN 1916:2002 and BS 5911-1:2002+A2:2010.

21.9.4 Oversize plastic pipes

Polypropylene pipes should meet the relevant provisions of BS EN 1852-1:1998.

All structured wall plastic pipes should comply with the relevant provisions of BS EN 13476-1:2007.

Structured wall pipes with a smooth external surface (includes spiral-wound HDPE pipes) should comply with the relevant requirements of BS EN 13476-2:2007.

Structured wall pipes with a profiled external surface (includes ribbed pipes) should comply with the relevant requirements of BS EN 13476-3:2007+A1:2009.

Note that these specifications are limited to a maximum diameter of 900 mm. The relevance of any particular clause should be carefully considered when applying the standards to larger diameter pipes.

Requirements for oversize plastic pipes are also described in UKWIR (2008) and relevant clauses from this document can also be used in specifications for SuDS.

Pipes manufactured using non-virgin materials should comply with PD CEN/TS 14541:2013.

21.9.5 Corrugated steel pipes

There are no British or European Standards for flexible steel pipes. Corrugated steel pipes used in SuDS should comply with the relevant requirements of the Specification for Highway Works, Series 2500, Special Structures (DfT, 2001).

21.9.6 Precast concrete box culvert sections (including flat-packed concrete panels)

Precast concrete box culverts should meet the requirements of BS EN 14844:2006+A2:2011. This provides guidance on design, manufacture and installation of culverts.

21.9.7 Glass-reinforced plastic (GRP) tanks.

There are no specific British or European standards that relate to the use of GRP tanks for storage of surface water. Important properties that should be considered by the designer and specified include:

- specific gravity of the materials
- tensile strength and modulus
- flexural strength and modulus
- impact strength
- shore hardness
- shear strength
- glass content
- coefficient of thermal expansion
- water absorption.

Relevant information from BS EN 13280:2001 should also be considered.

21.9.8 Hybrid structures using reinforced earth walls and concrete roof panels

The concrete roof panels should comply with the relevant European standards for precast concrete, BS EN 13369:2013.

The reinforced earth construction should comply with the relevant Eurocodes for aggregates and geogrids. Geogrids should be CE marked to a recognised harmonised standard or via the European Organisation for Technical Assessment. The geogrids should comply with BS EN 13251:2014+A1:2015. The values of properties that have been used in any stability assessment should be clearly stated in the specification for each project.

21.9.9 Upstream treatment and inlets

SuDS should be designed to prevent or minimise the risk of sediment ingress into tank systems, especially geocellular and arch structures. This is because there is limited access, and it can be difficult to remove sediment build-up once it enters those types of structure. It is especially important to make sure that runoff during the construction phase is prevented from entering geocellular and arch tanks, as this has a very high sediment load as well as other debris, which could affect the operation of the tank (**Chapter 31**).

As a bare minimum, for any tank a sediment sump should be included within the design immediately upstream of the tank for on-line systems (eg if water flows through a geocellular tank). Sediment traps should not be allowed to overfill, as this may cause sediment to be carried into the distribution pipework. Where sediment cannot be easily removed from tanks, a more effective treatment system should be provided that is not as reliant on maintenance for its operation (eg filtration into a tank through overlying soil or using treatment channels). Some systems are configured to enable inspection and jetting of sediments that migrate from upstream pre-treatment (**Figure 21.19**). It is important to ensure that practical access can be gained to the system.

Off-line storage systems are less prone to sedimentation (ie day-to-day flows carrying the majority of sediment loads bypass the tank). These types of system include the 2D systems that are filled via perforated pipes as water backs up in the pipe. However, if the water has to pass from the perforated pipe through the 2D tank to another pipe, they are classified as on-line and thus carry the same risks. The risk of clogging of any geotextiles that surround pipes or gravel trenches in those systems should also be considered.

As a secondary precaution against loss of performance due to sedimentation in geocellular tanks, it is common to provide slightly oversized tanks to allow for some volume loss over time (typically 10% extra volume is provided by rounding up the size of a tank to form a cuboid structure, so there is no extra cost for this). **Table 21.2** provides potential sediment loads and the potential loss of storage that could be allowed for over a 50-year operation period, although this is site specific and will depend on the volume of storage being provided for each unit area of contributing catchment.

Figure 21.19 Some system configurations allow jetting equipment to move within the structure (courtesy Aco Limited)

Sediment forebays or tunnels can also be provided within tanks, or can be combined with an upstream and downstream manhole to trap sediment in a location that is accessible. **Figure 21.20** shows forebays in a geocellular construction combined with manhole construction at either end of the tank. However, these should not be considered a replacement for effective upstream treatment. The forebay should be easily accessible to clean out. This is the preferred option rather than inspection channels through the tank because the forebay should be accessible for easy visual inspection without the use of CCTV. Many manufacturers can supply specific inspection/forebay modules to incorporate into a tank.

TABLE 21.2 Sediment loading and potential loss of storage (from O'Brien *et al*, in press)

Location	Worse case silt load (TSS)[1] (kg/ha/yr)	Maximum potential loss of storage after 50 years (%)
Highways	723	7
Commercial	840	8.5
Low density residential	340	3
High density residential	755	8
Car parks	762	8
Roofs	216	2

Note

1 D'Arcy *et al* (2000) provides typical silt loadings in terms of total suspended solids

21.9.10 Outlets

When used for storage, the structure should have an outlet connecting to the downstream drainage system or watercourse. All systems should be designed to include an emergency or bypass system to safely pass flows that exceed the design event, but care should be taken that extreme flood discharges do not affect downstream buildings and structures.

21.10 MATERIALS

For all types of tank, good quality backfill/bedding/surround is recommended to ensure that adequate compaction is achieved around the tank and that no voids are left in the backfill.

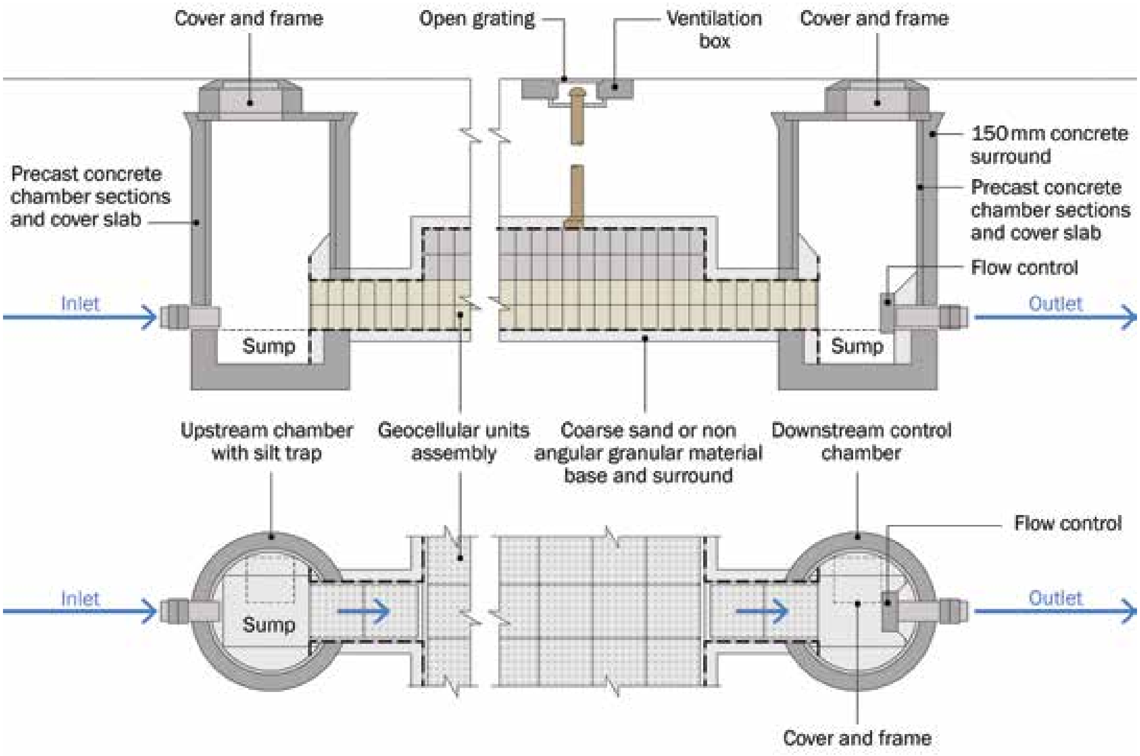

Figure 21.20 Example of sediment forebay

The specifications generally used for backfill for geocellular units are Class 6N or 6P material for storage or Type B drainage material in soakaway applications (DfT, 1998). However, there are many other types of backfill. Pipes should use the types of materials assumed in the structural design for the bedding and surround.

Uncontrolled site-won materials are not recommended in most installations as they may contain debris, large stones or contaminated materials that could damage the units or penetrate the membranes. There are examples of failure of geocellular tanks where as-dug very soft clay was used as backfill, with the material being weaker than granular material assumed in the design. This resulted in greater lateral pressures on the side of the tank and contributed to its failure. Similar problems have occurred with pipes.

On large projects that have materials sorting and recycling facilities, treated site granular waste could be utilised once it conforms to the correct specification by being crushed and sieved for example. Care would have to be taken to ensure that the source was not contaminated with substances that could damage the installation.

21.11 LANDSCAPE DESIGN AND PLANTING

The main concern with vegetation is to ensure that the tank will not be damaged by tree roots. If necessary, the tank can be wrapped in a root barrier, or planting of trees close to the tank can be restricted – but in practice this can be difficult to enforce once a development is completed or where installed close to existing retained vegetation.

21.12 CONSTRUCTION REQUIREMENTS

All tank structures should be constructed in accordance with the good practice guidance for the particular type of pipe or material and standard drainage requirements (eg WRc, 2012). Analysis and experience have shown that the successful performance of any systems depends upon the type and depth of bedding and backfill, and care in installation.

The key to the success of a tank system project is a "joined-up thinking" approach between the parties involved. In a typical overall development there can be a wide variety of people or organisations involved in the design and construction. Some of those involved in a scheme may lack an appropriate level of knowledge and there is often a non-formalised design and construction process, which can lead to a lack of appropriate communication between the parties. Many of the past failures and examples of poor performance of modular surface water storage using geocellular units and arches can be attributed to poor communication. In order to achieve the necessary communication between the parties to ensure success, it is recommended that the existing legal framework and legislation of the CDM 2015 are fully utilised (see O'Brien *et al*, in press).

▶ Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**.

A construction phase health and safety plan is required under CDM 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

▶ Generic health and safety guidance is provided in **Chapter 36**.

All attenuation systems should be tested to make sure they are watertight. Pipes and culverts should meet the requirements in WRc (2012). Systems wrapped in membranes should have membrane and welds tested as installation progresses.

21.12.1 Handling and protection

The following checks should be carried out:

- Quality assurance checks should be carried out on the delivery of products to site and the installation. This may vary from simple visual observations (eg confirm site geology, check backfilling of excavations) to monitoring to confirm the performance of the tank for high risk installations.
- Check for damage by careless handling or storage on site. Although not usually structurally significant, if damaged products were used at the edge of a tank, this could cause a tear to any geomembrane or geotextile surround or could cause a leak at pipe joints.
- Check that storage on site is on a flat surface and that the manufacturer's recommendations regarding storage are being followed (maximum number of layers, avoid extended exposure to sunlight, protect from damage etc).

Runoff should be prevented from entering tanks during construction, unless this has specifically been allowed for, and sediment can be removed afterwards. Alternatively, and only if the design allows, a flushing operation may be required before commissioning, to ensure that all sediments have been removed from the system.

21.12.2 Excavation

The excavations in which tanked systems are constructed should be kept free of both groundwater and surface water runoff. Groundwater control is critically important for the ease and safety of construction, as well as for excavation stability but also for the stability of the tank unit (particularly for geocellular systems). Ingress of groundwater into an excavation containing a sealed attenuation tank may lead to failure of the tank by floatation before the backfill is placed over it. There are instances where surface rainwater from the top of the tank alone has runoff into the excavation and caused flotation during construction (**Figure 21.21**).

Figure 21.21 Flotation and movement caused by rainwater in excavation (courtesy EPG Limited)

Geocellular units and plastic pipes, for example, are very light and typically weigh about 45 kg/m^3. Only a very small depth of water is required in the base of an excavation to cause a tank, before backfill placement, to float.

21.12.3 Formation preparation

The base of the excavation on which the tank is founded should be clean, firm and level. If this is not the case then the units/sections/lengths of pipe will be difficult to place, as they become displaced on an uneven surface. This can have structural implications and could cause tearing of any membrane or geotextile surround or leaking joints. Normally a blinding or bedding layer of granular material (sand or gravel) is placed in the bottom of the excavation.

The base of the excavation should be inspected to ensure that the materials are of sufficient strength to support the installation and that there are no large stones or other objects that could damage the tank or penetrate any surrounding geotextile or geomembrane. For clays, a shear strength of greater than 40 kPa should be adequate. In poor ground conditions, removal of soft materials and/or extra granular or blinding materials may be required to form an adequate foundation. Sub-base replacement geocellular units that act as a raft can often support light loading on soils with a CBR value of 2% and have been used to construct “floating” permeable pavements over very poor ground in the Netherlands.

Also, the base conditions and loadings/support should be uniform across the installation. Most types of tank can be particularly vulnerable to load concentrations that could occur if a tank spanned across old foundations creating a hard spot, for instance.

21.12.4 Placing and assembling units/pipes/products

All types of tanks should be placed and assembled in accordance with the relevant standards, specifications and guidance.

Where geocellular systems are stacked more than one layer high, care should be taken to ensure that the units are correctly positioned on top of each other with relevant layer connectors used, if required, to ensure adequate load transfer from the top to the base of the installation. Some crate systems use pillars of one form or another, and failure to ensure that these pillars are positioned directly above each other will lead to a lower load capability of the installation.

21.12.5 Backfilling

For any tank the bedding, backfill or surround is critical to the structural performance, and it should comply with all assumptions made by the designer.

In untrafficked situations, excavations can generally be backfilled with selected, as-dug material that does not contain large particles or sharp materials. It should then be well compacted. In trafficked areas, the use of well-compacted backfill and cover is particularly important, and the material should, typically, be selected in accordance with standard highway or drainage works specifications (eg HA, 1996b, or WRc, 2012). Use of poor quality backfill can significantly increase lateral earth pressures on tanks, and cause collapse. Running heavy plant over constructed tanks or stockpiling material over them during construction, when such loads have not been included within design calculations, can also cause collapse, especially if temporary cover during site works is less than the final design cover depth. Any geomembrane wrapping may need to be protected from the backfill by a geotextile fleece in some instances. In all cases, advice should be sought from individual manufacturers regarding specific recommended installation and cover depths.

Compacting backfill around the sides of some types of tank with plant that is too heavy can cause large deflections in the sides, with a resulting structural implication. Lightweight man-operated plate compactors are generally recommended for the perimeter and the first layers above the tank, as compaction can apply high lateral pressures. Where compaction pressures have to be avoided, but a stable backfill is required, weakly cemented no fines concrete can be considered.

Heavy vibrating rollers are definitely not recommended around plastic pipes or tanks due to the high pressures that they can generate. Thin layers with smaller plant are recommended. DfT (2009) should be referred to for guidance for plant and methods for achieving compaction. The manufacturers' recommendations usually limit plant size above geocellular units to no more than 2300 kg/m width. However, the loading resulting from this will still need to be checked in the design. If such plant is to be used adjacent to the units, the resulting compaction pressures need to be checked.

Any arch or flexible pipe structures depend on the even resistance provided from soil or aggregate on both sides of the arch/pipe for their structural capacity. Even slight differences in the level of filling on each side of the arch/pipe as it progresses could potentially cause uneven deflections and increase the stress within the structure above design values. Close supervision during backfilling is therefore vital. The backfill around geocellular tanks should also be brought up evenly around all sides.

Bedding directly below a concrete pipe should have minimal compaction. The fill at the side of the pipe should be well compacted to a level 300 mm above the crown of the pipe. Only light compaction should be applied to the backfill directly over the crown of the pipe to a point 300 mm above it. With reasonable workmanship and supervision, the bedding factors used in the design should be relatively conservative.

21.12.6 Wrapping

All storage tanks should be watertight in accordance with the relevant standards. Geocellular and similar structures using geomembranes to hold water should be sealed in accordance with waterproofing standards (ie welded joints rather than adhesive taped) and the integrity of the seal checked on site through the use of non-destructive testing, to ensure that it is leak-proof. Advice on appropriate integrity and seam tests for geomembranes, that could be adapted for testing membranes around storage tanks, is provided in Mallett *et al* (2014). Care needs to be taken during installation to protect against damage of both the tank structure and the geotextile and the geomembrane wrapping. Follow-on trades can also cause damage and put the integrity and performance of the structure at risk.

21.13 OPERATION AND MAINTENANCE REQUIREMENTS

Regular inspection and maintenance is required to ensure the effective long-term operation of below-ground storage systems. Maintenance responsibility for systems should be placed with a responsible organisation. **Table 21.3** provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

Maintenance Plans and schedules should be developed during the design phase, and will be specific to the type of tank that is adopted. Specific maintenance needs of the system should be monitored, and maintenance schedules adjusted to suit requirements. Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

▶ Generic health and safety guidance is provided in **Chapter 36**.

TABLE 21.3 Operation and maintenance requirements for attenuation storage tanks

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Inspect and identify any areas that are not operating correctly. If required, take remedial action	Monthly for 3 months, then annually
	Remove debris from the catchment surface (where it may cause risks to performance)	Monthly
	For systems where rainfall infiltrates into the tank from above, check surface of filter for blockage by sediment, algae or other matter; remove and replace surface infiltration medium as necessary.	Annually
	Remove sediment from pre-treatment structures and/or internal forebays	Annually, or as required
Remedial actions	Repair/rehabilitate inlets, outlet, overflows and vents	As required
Monitoring	Inspect/check all inlets, outlets, vents and overflows to ensure that they are in good condition and operating as designed	Annually
	Survey inside of tank for sediment build-up and remove if necessary	Every 5 years or as required

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Regulations

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BS 8006-1:2010 *Code of practice for strengthened/reinforced soils and other fills*

BS 9295:2010 *Guide to the structural design of buried pipelines*

European Standards

BS EN 752:2008 *Drain and sewer systems outside buildings*

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BS EN 1916:2002 *Concrete pipes and fittings, unreinforced, steel fibre and reinforced*

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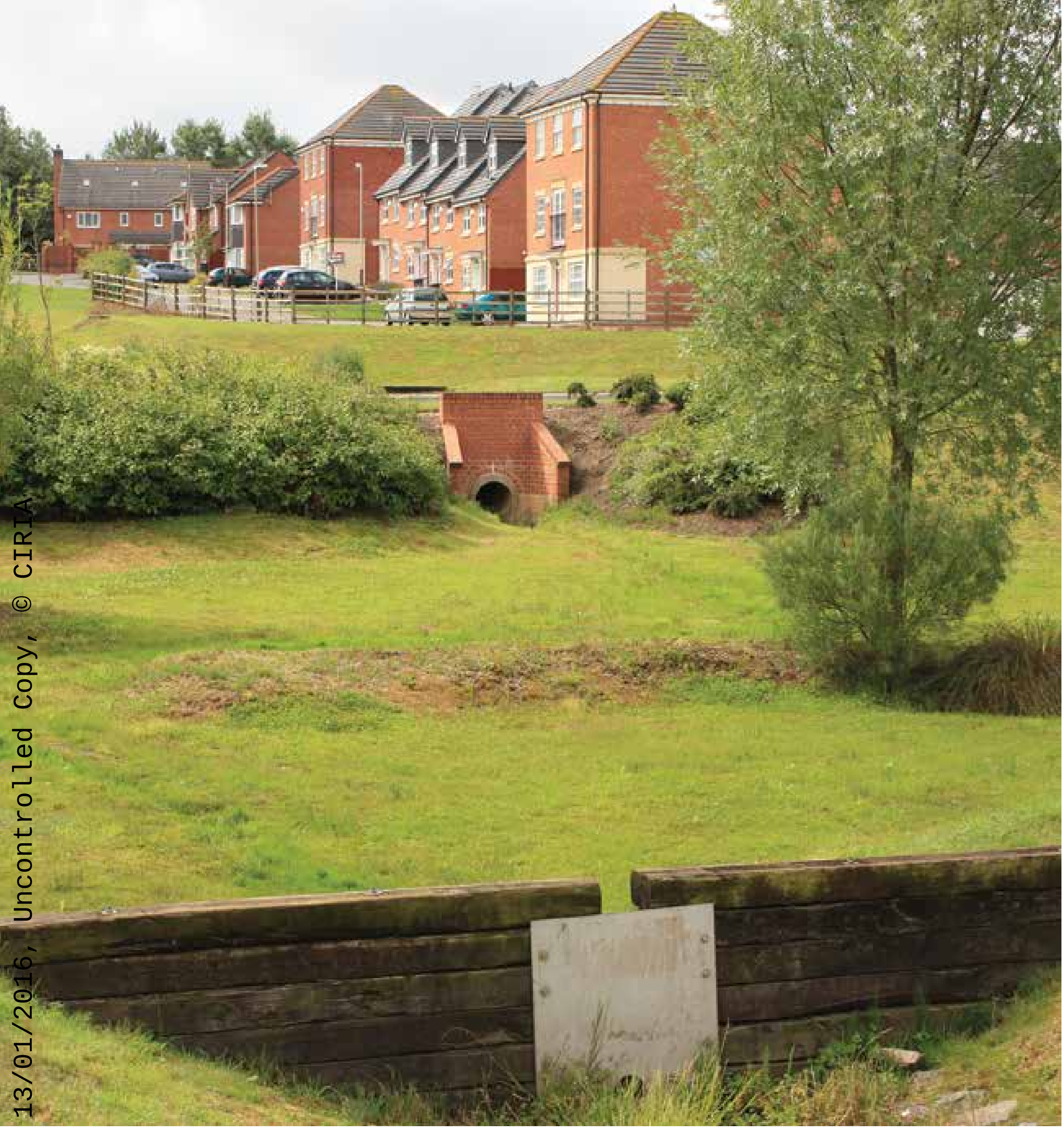

22 DETENTION BASINS

Contents

Chapter 22

Detention basins

This chapter provides guidance on the design of detention basins – landscaped depressions that are normally dry except during and following rainfall events, designed to attenuate runoff and, where vegetated, provide treatment.

▸ *Appendix C, Section C.5.3 demonstrates how to design a detention basin for a supermarket.*

22.1 GENERAL DESCRIPTION

Detention basins are landscaped depressions that are normally dry except during and immediately following storm events. They can be on-line components where surface runoff from regular events is routed through the basin and when the flows rise, because the outlet is restricted, the basin fills and provides storage of runoff and flow attenuation. They can also be off-line components into which runoff is diverted once flows reach a specified threshold.

Detention basins can be vegetated depressions (that can provide treatment when designed to manage regular flows) or hard landscaped storage areas (that will tend not to provide any treatment and are normally designed as off-line components).

Where the basin is vegetated, the soil surface can absorb some runoff, so can be used to support the prevention of runoff from the site for small rainfall events (Interception), provided that small amounts of infiltration would not pose a risk to groundwater. The principal water quality benefits of vegetated detention basins are associated with the removal of sediment and buoyant materials, but levels of nutrients, heavy metals, toxic materials and oxygen-demanding materials may also be significantly reduced. The water quality benefits of a vegetated detention basin increase as the detention time for an event becomes longer. Where designed appropriately, some or all of the basin area can also be used as a recreational or other amenity facility (**Figure 22.1**).

Figure 22.1 Detention basin with landscape design providing attractive amenity space, Hamilton, Leicester

Off-line detention basins will normally have an alternative principal use: either as an amenity or recreational facility, or as part of urban hard landscaping.

Where there is no upstream pre-treatment, on-line detention basins should include a forebay to try to contain accumulating sediments, although this can result in unusable and unattractive areas, which may not be acceptable for public open space.

For maximum pollutant removal effectiveness in vegetated basins, flows should be distributed across the full width of the basin. However, where there are concerns about keeping a proportion of the base of the basin dry, a discrete area of the basin can be lowered to constrain frequent events within a specified area. Constraining low flows to specific routes can provide multi-functionality benefits and reduce the risks of the base of the basin becoming wet and boggy.

Vegetated detention basins can be designed with a small permanent pool at the outlet to help prevent resuspension of sediment particles by high intensity storms and to provide enhanced water quality treatment for frequent events. Any open water element would require effective integration into the landscape, and consideration would be required of the risk of the pond drying out during the summer, potentially causing plant die off. An ephemeral pool could be valuable from a biodiversity perspective, but it may look unattractive, and this requires careful consideration by the designer (eg evaluation of appropriate minimum depths or appropriate marginal planting).

Detention basins are frequently used for temporary sediment control during construction. It is essential that they are reinstated or reconstructed at the end of construction and before adoption by the maintaining authority.

Figure 22.2 provides a typical plan view and profile for the design of a detention basin.

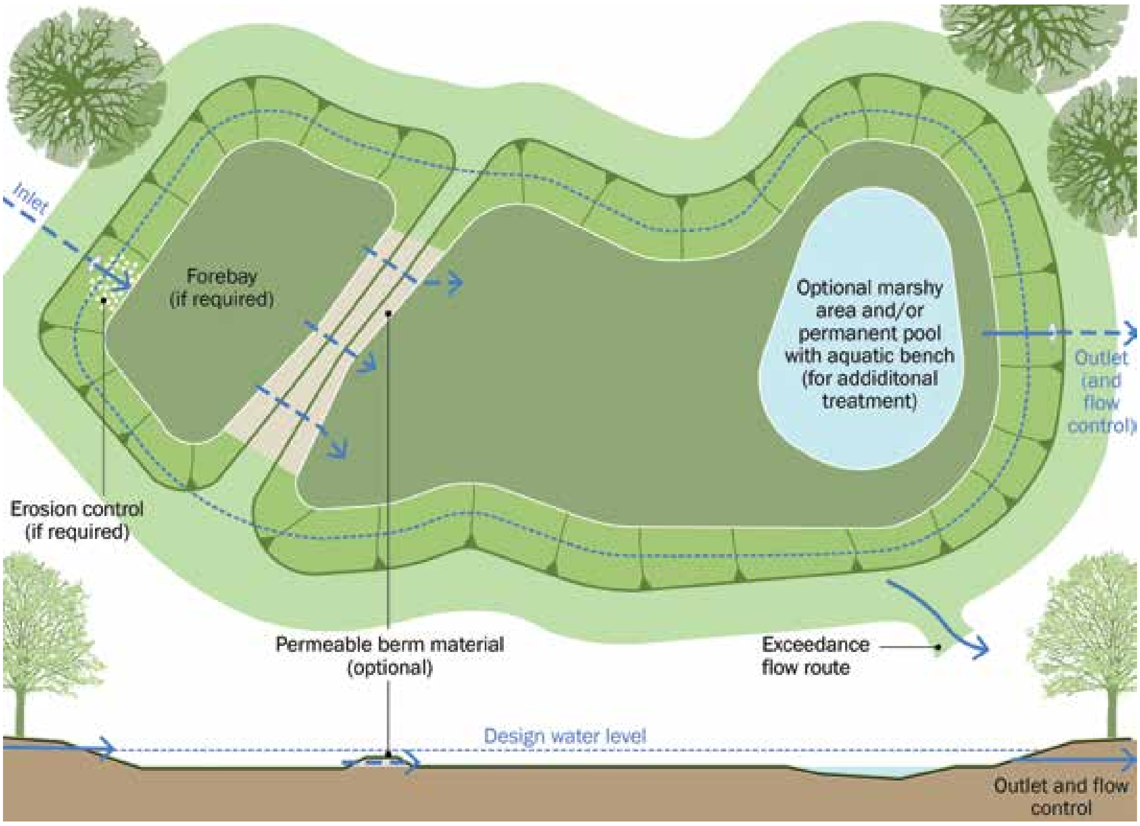

Figure 22.2 Plan and elevation of vegetated detention basin

22.2 GENERAL DESIGN CONSIDERATIONS

The form and aesthetic appearance of the component will depend on specific site characteristics, landscape/amenity objectives and development design criteria. Unless used for a sports pitch or to fit into some specific landscape, vegetated detention basins should not normally follow a geometric profile, but they should have edges with curves and undulations to produce an aesthetically interesting and natural-looking feature.

The maximum depth of water in the basin should not normally exceed 2 m in the most extreme design event. However, many authorities will require a much lower maximum depth, for safety reasons.

The bottom of any vegetated basin should be fairly flat with a gentle slope (no more than 1 in 100) towards the outlet, to maximise contact of runoff with the vegetation and to prevent standing water conditions from developing. Areas above the normal high water elevations of the basin should also be sloped towards the basin to allow effective drainage. The base of the basin can also be provided with a layer of engineered soil or underdrains to maintain a firm and dry surface.

The recommended length/width ratio for on-line vegetated detention basins is between 3:1 and 5:1. Inlets and outlets should be placed to maximise the flow path through the facility. Contoured bases can be effectively used to define and lengthen areas that are likely to be wetted regularly.

A liner may be required to maintain the water level in any small permanent water feature, prevent infiltration of runoff where water quality risk assessment indicates that this is not acceptable and/or to protect an underlying aquifer.

Where swales are used as low flow channels, their design should follow guidance set out in **Chapter 17**. Filter trenches could also be used to convey low flows, but these will require very effective upstream pre-treatment so that the risk of reduced performance due to blockage is controlled, and will deliver limited treatment themselves. The use of filter trenches also carries high maintenance and erosion risks associated with movement of filter material during moderate to high flow events, and any designs should ensure that such risks are adequately managed.

Any embankment should be designed in accordance with best practice, as described in Kennard *et al* (1996). Designs should meet all requirements of the Reservoir Act 1975, as amended by the Flood and Water Management Act 2010. Even if the impounded basin does not come within the thresholds of the Reservoirs Act, owners still have statutory duties for the safety of others under legislation such as the Health and Safety at Work (etc) Act 1974 and the Building Act 1984. Consideration should be given to the safe routing of floodwater when the design event is exceeded, and to mitigating the risks of potential embankment failure.

Side slopes of any vegetated basin should not usually exceed 1 in 3 unless special site and/or safety arrangements allow for steeper slopes (eg steeper slopes may be acceptable for very shallow basins). Slopes should be no steeper than 1 in 3 wherever mowing is required, to reduce the risks associated with maintenance activities. Flatter slopes tend to improve the aesthetics, at the expense of extra land-take. Hard landscaped basins will often have vertical sides, but will tend to be very shallow.

There should always be appropriate access to the detention basin for maintenance activities such as grass cutting and sediment removal to be undertaken, and to all inlets, outlets and control structures. Maintenance access can often be integrated with routes for general public access, which can help in discouraging heavy use of wider basin slopes that can potentially create erosion risks.

Health and safety risk management design guidance is provided in **Chapter 36**. Safety principles in relation to public use are set out in **Section 22.6**.

22.3 SELECTION AND SITING OF DETENTION BASINS

Detention basins are generally applicable to most types of development, and can be used in both residential and non-residential areas. They are also appropriate for use in retrofit situations (where existing drainage network levels and land availability allow).

They can often be designed as multi-functional spaces, creating an open area within a development, part of which can be made available for recreational purposes. Roundabouts can also often provide suitable space that is redundant within the existing or proposed development landscape.

Figure 22.3 Detention basin serving a housing estate, Stirling (courtesy Abertay University)

Figure 22.4 Detention basin in a roundabout, DEX, Dunfermline (courtesy Abertay University)

Historic records of groundwater level should be checked to ensure that during periods of high groundwater, the storage capacity of the detention basin is retained and that hydraulic connectivity between the surface water runoff and the groundwater is acceptable from a water quality perspective. If a liner is used, there is a risk that the liner may "float" during periods of high groundwater levels. A seasonally high groundwater table may not always impede the proper functioning of the facility, but it can result in a muddy base that may be considered unattractive if not developed into a permanent wetland feature.

Unlined detention basins should not be used on brownfield sites unless it has been clearly demonstrated that there is no risk of groundwater pollution. Any excavation or earthmoving processes required should be assessed to ensure that mobilisation of contamination does not occur. Unlined detention basins should not be used to treat runoff from hotspots if there is a risk of groundwater pollution.

For catchments of less than three hectares, outlet throttle diameters may have to be very small (ie < 150 mm diameter) in order to achieve pre-development outflow rates. This may mean that they risk clogging and special attention should be given to the design of the outlet area and flow control. Where a micropool at the outlet is required, the soil below the pool area should be sufficiently impermeable to maintain the permanent pool, unless a continuous baseflow or high groundwater table is present. In highly permeable strata, a liner will be required to prevent the pool from drying out.

22.4 HYDRAULIC DESIGN

22.4.1 General

Guidance on hydraulic criteria and design standards is given in **Chapter 3** and methods for sizing storage are presented in **Chapter 24**. Detention basins can be sized to provide flood attenuation for all events to meet the site standards of service (up to the 1:10, 1:30 or 1:100 year events), if required, with discharges being constrained to the equivalent greenfield (or other agreed) rates. Consideration should be given to larger events, as these will need to be safely routed downstream. Basin volumes may need to be increased if additional storage is required to deliver volumetric control of runoff for the 1:100 year event (**Section 22.4.4**).

Detention basins may be constructed as on-line or off-line facilities. On-line facilities have surface runoff routed through them during storm events. They have a restricted outflow that allows the basin to fill, thus attenuating flows. Off-line facilities usually receive runoff via a flow diverter or overflow, by which flows in excess of a threshold value are diverted from the main flow path into the detention basin and temporarily stored. The water from the detention basin is passed back into the main system when the inflow falls below the diversion threshold. Off-line detention basins should be avoided where treatment of the runoff is important, because it is the lower flows that will generally pose the highest pollution risk.

22.4.2 Interception design

Vegetated detention basins can deliver some Interception because there tends to be no runoff from them for the majority of small rainfall events. The water soaks into the basin topsoil layer and is removed by evapotranspiration and even very small amounts of infiltration (where this is allowed). The extent of the volumetric reduction in runoff to surface waters will depend on the infiltration rate of the surrounding soil, the catchment area, the area and depth of the system, the type of vegetation and the climate.

Where there is infiltration capacity, infiltration is acceptable, and the detention basin is designed to facilitate even limited infiltration, then a check should be made to determine whether the basin is able to dispose of 5 mm rainfall depth over the contributing catchment area.

Where there is no infiltration, but the natural surface soils (or imported/re-engineered soils) have water storage capacity, then Interception design should follow the principles set out in **Section 24.8**. Hard landscaped basins will not deliver Interception.

22.4.3 Peak flow control design

Detention basins can help reduce flow rates from a site by controlling the discharge rate and allowing the basin storage to fill during storm events. The required peak flow control and storage volume can be determined using standard hydraulic assessment (**Chapter 24**).

22.4.4 Volume control design

Detention basins do not normally contribute to volumetric control of runoff, but can be used as Long-Term Storage areas, or to deliver further attenuation where Long-Term Storage is not practical (**Chapter 3**). Assessment of volumetric control should follow the normal hydraulic assessment methods in **Chapter 24**.

22.4.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the detention basin. This can be achieved by installing an overflow pipe, channel or weir/overflow structure above the design water storage level to convey excess flows downstream.

The exceedance flow capacity of the overflow should be confirmed using normal hydraulic assessment methods and analysis (weir, orifice and pipe flow). Exceedance flows beyond the capacity of the overflow should also be confirmed.

Any exceedance flow structure should be located as close to the inlet as possible to minimise the flow path length for above-capacity flows, thus reducing the risk of scouring. See **Section 22.8.2** on outlet design for details. The overflow should not impede access to any inlet/outlet/control structure that manages more frequent flows.

Detention basins are often used as off-line systems to manage exceedance flows from the main surface water management system. In this case, they will normally have an alternative principal use, for example as a dedicated amenity/recreational facility. Further guidance on designing for exceedance flow management is set out in **Section 24.12**.

22.5 TREATMENT DESIGN

Vegetated detention basins can help retain runoff from small events on site (ie deliver Interception, **Section 22.4.2**), helping reduce the contaminant load via volumetric control. They can also treat the residual runoff, primarily via the gravitational settling of particulate pollutants, although some filtration will occur through the vegetation on the basin base and underlying soils together with biodegradation and photolytic breakdown of hydrocarbons during the drying processes between runoff events.

Figure 22.5 Example of urban hard surfaced off-line detention basin with geometric design to enhance amenity use, Rotterdam, the Netherlands (courtesy pallesh+azarfane)

The key to delivering reasonable levels of treatment using vegetated detention basins is the effective capture and management of sediments, and the distribution of inflows across a sufficient width of the detention basin – thus maximising the potential vegetated filtration area. Small ponds can be incorporated at the outlet to reduce the risks of resuspension of sediment from larger events and can also improve the water quality performance by concentrating finer sediment (**Section 22.10**).

Good pollutant removal performance is required for all runoff events up to and including events which occur, on average, about once a year (termed here the 1:1 year return period event). The duration of this event should be the relevant critical duration for the detention basin. For this water quality design event (for a vegetated basin):

- the depth of flow should be maintained below the height of vegetation (ie usually < 100 mm)
- the maximum flow velocity in the basin for such an event should be 0.3 m/s to ensure adequate runoff filtration
- the time of travel of runoff from inlet to outlet of the basin (residence time = length/velocity) should be at least 9 minutes.

To calculate the average velocity of flow in the basin, Manning's equation should be used (**Section 24.11.1**). The Manning's "n" value, or the "roughness coefficient" indicates to what extent the surface of the basin will resist flow and is critical in its sizing. The coefficient varies with type of vegetative cover and the flow depth and a suggested relationship between flow depth and Manning's "n" for grass channels is given in **Chapter 17, Figure 17.7**.

Evidence of the pollutant removal efficiencies of vegetated detention basins is presented in **Chapter 26, Annex 3**.

22.6 AMENITY DESIGN

Detention basins can be important parts of the landscape design for public open space – defining the topography for green or hard landscaped areas. Basin design can take many forms, from naturalistic and irregular to formal and geometric. This will depend on the planned future use of the space and the landscape, amenity and biodiversity objectives for the site. The value of basins can often be enhanced with footpaths or cycle paths, and enhanced with structural and diverse plants, wetland planted areas and wildflower mixes to enhance their beauty and amenity contribution.

Detention basins may be constructed to serve more than one purpose, and can be used as car parks, playgrounds or sports fields. When constructed for multiple purposes, the detention basin should be usable for the function other than surface water detention for most of the time. Where multi-functional use is intended, the recreational area should normally have a relatively low flooding frequency such as 1–5 year return period, depending on its use. Interpretation boards explaining that the area is part of the drainage system and that it could be filled with water may also be required.

Where detention basins form an integral part of public open space or recreational play areas, it is crucially important that those using or living near the facility are aware of its functionality and value. How to involve the community in this way is discussed in **Chapter 34** and planting best practice is presented in **Chapter 29**.

Fencing is generally not desirable as it may reduce the amenity benefits provided by the detention facility, provide a barrier to easy maintenance and provide a trap where litter and dead vegetation can collect. Where fences are required, they should be low (toddler-proof), but allow movement of wildlife. Gentle slopes and appropriate planting can contribute to minimising public safety risks.

Inlet and outlet pipes and culverts should not be accessible. The headwalls of large pipes should be fenced to prevent accidents and deter access. Grilles should also be considered to prevent entry into the pipe but these tend to clog rapidly, triggering more regular maintenance requirements and potentially affecting hydraulic performance (**Chapter 28**).

Life-saving equipment should only be provided where required by the risk assessment, and operators will have to inspect such equipment on a regular basis to minimise any liability risks.

22.7 BIODIVERSITY DESIGN

By following the biodiversity criteria in **Chapter 6**, biodiversity value of any SuDS component can be maximised. Vegetated detention basins can include a variety of structurally diverse planting that will help make a positive contribution to urban biodiversity – providing habitat and food for invertebrates and birds. Some plants and animals specifically require ephemeral water bodies as part of their life cycle, and suitable wildflower mixes can provide important nectar sources for insects. Where space allows, multiple basins of varying size and shape should be created, and consideration given to the inclusion of shelves and shallow graded sides, undulating surfaces and convoluted edges to provide the greatest wildlife value. The ecological value of the system can also be enhanced by including micropools or wetland zones at the base. Further guidance is given in **Chapters 6 and 29**.

22.8 PHYSICAL SPECIFICATIONS

22.8.1 Pre-treatment and inlets

For on-line systems – the number of inlets to the basin should be limited, preferably to one. The flow path length should be maximised from inlet to outlet for all inlets.

For basins serving large developments, a sediment forebay or upstream pre-treatment component will improve the water quality performance of a vegetated detention basin and reduce long-term maintenance requirements. The plan area of the sedimentation bay should be at least 10% of the total basin area and could consist of a separate basin or be formed by building an earth berm, stone or rock-filled gabion or rip-rap across the upstream portion of the basin. For systems with multiple inlets, pre-treatment should be provided for each inlet that is likely to contribute a significant sediment load. Each forebay should be accessible and easily maintained. Consideration should be given to installing a fixed sediment depth marker in the forebay to measure sediment deposition with time. This will assist with the development of appropriate maintenance schedules.

The energy of the incoming flows should be dissipated to minimise the risk of scouring and erosion. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems. The scale of the erosion mitigation system required will be dependent on incoming flow velocities, but should be physically and aesthetically proportionate to the size of the basin. Safety grilles may be required if inlet pipe diameters allow public entry, but they tend to increase the risks of blockage and can present a hazard in themselves; so, wherever possible, inlet infrastructure should be designed so that they are not required. Inlet designs should blend with the landscape – detailed guidance on inlet designs can be found in **Chapter 28**.

22.8.2 Underdrains and outlets

At the outlet, there will normally be a requirement for some form of flow control system. A manhole-type outlet structure can accommodate a variety of outlet control mechanisms. Detention basins will generally require a non-clogging, variable flow rate control structure at the outlet, together with an emergency overflow. Low flow controls are generally provided via protected orifices, which can then be combined with overflow channels and overflow weir sections and/or culverts for larger events. Multiple orifices or pipe outlets can be used to achieve the same objectives. Trash screens are not recommended, but where grilles are necessary to prevent access into the pipework, they should be designed so that debris does not unduly obstruct or reduce design flow rates.

Energy dissipation may be required downstream of the outlet to prevent scouring and erosion, but this will depend on the outflow discharge rates, the outfall design and the vulnerability of the receiving watercourse or lake to erosion.

For outlet pipes through embankments, seepage control in the form of collars may need to be provided.

The design of exceedance flow management components is discussed in **Section 22.4.5**.

Outlet design should be appropriate and complementary to the local landscape. Detailed guidance on outlet designs can be found in **Chapter 28**.

22.9 MATERIALS

There are no unique materials that are used in detention basins. Subsoil, topsoil, geotextile, geomembrane and filter drain aggregate specifications are provided in **Chapter 30**.

22.10 LANDSCAPE DESIGN AND PLANTING

Detention basin design should take account of the local landscape and local environment. It should be site specific, and individual designs should be developed to deliver the required amenity and biodiversity objectives for the site.

Detention basins are typically grassed structures, although some other vegetation can enhance the appearance and amenity value of the basin, stabilise side slopes and prevent erosion, serve as wildlife habitat, and partially conceal unsightly litter and debris. It can also help increase the effectiveness of sediment settling by slowing the flows across the basin.

Topsoil depths will vary for different planting proposals, so 100 mm of subsoil may be suitable for wildflower meadow surfacing, 150 mm topsoil is required for amenity grass and 450 mm will be necessary for planted areas. This should be a high-quality topsoil with a loam or sandy loam texture.

Where small pools are included as a feature of the basin, they are normally planted with wetland vegetation species. There is normally a risk that the pool may dry out during summer months, so pool depths and marginal plants should be selected to reduce any potential consequences.

Reinforced grass may be required for maintenance routes where vehicular access is anticipated.


Figure 22.6 Examples of detention basins with easy access for maintenance (courtesy Peterborough City Council and Kent County Council)

22.11 CONSTRUCTION REQUIREMENTS

The bottom and side slopes of the basin should be carefully prepared to ensure that they are structurally sound and the grading should be uniform and smooth to the correct slope so that water does not pond in depressions and to minimise the risk of channelling and erosion through preferential flow paths. Checks should be made that any embankment structures meet their design criteria. The preparation should also ensure that the basin will satisfactorily manage design flows without significant erosion damage.

Backfilling against inlet and outlet structures needs to be controlled so as to minimise settlement and erosion. The soils used to finish the side slopes need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

During the SuDS establishment phase, runoff from bare soils should be minimised. For example:

- vegetation on slopes should be rapidly established
- base-of-slope trenches should be introduced to retain the inevitable runoff of sediments
- construction should be timed to avoid autumn and winter when high runoff rates are to be expected.

Detention basins may be used to manage construction runoff and trap construction sediments, provided they are fully rehabilitated to original design formation levels before handover.

Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**. Generic health and safety guidance is provided in **Chapter 36**. A construction phase health and safety plan is required under the Construction (Design and Management) Regulations (CDM) 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

22.12 OPERATION AND MAINTENANCE REQUIREMENTS

Detention basins will require ongoing regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of bioretention systems is dependent on maintenance, and robust management plans will be required to ensure maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance.

Maintenance of detention basins is relatively straightforward for landscape contractors, and typically there should only be a small amount of extra work (if any) required for a SuDS detention basin over and above what is necessary for standard public open space.

Maintenance responsibility for a basin should always be placed with an appropriate organisation. Adequate access should be provided to all detention basin areas for inspection and maintenance, including for appropriate equipment and vehicles. Litter and debris removal should be undertaken as part of general landscape maintenance for the site and before any other SuDS management task. All litter should be removed from site.

The major maintenance requirement for detention basins is usually mowing. Regular mowing in and around detention basins is only required along maintenance access routes, amenity areas (eg footpaths), across any embankment and across the main storage area. The remaining areas can be managed as “meadow”, unless additional management is required for landscape/amenity/recreational or aesthetic reasons.

Mowing should ideally retain grass lengths of 75–150 mm across the main “treatment” surface to assist in filtering pollutants and retaining sediments and to reduce the risk of flattening during runoff events. Longer lengths of vegetation may be appropriate, depending on the functionality of the component, and its associated design criteria and are not considered to pose a significant risk to functionality.

Shorter lengths may be required when recreational facilities form part of the basin, but in this case the basin will be dealing with exceedance flows only and not treatment.

Grass clippings should be disposed of off-site or outside the detention basin area to remove nutrients and pollutants. Where a detention basin has a small permanent pool at the outlet, its submerged and emergent aquatic vegetation should be managed as for ponds or wetlands. Plant management, to achieve the desired habitat effect, should be clearly specified in a maintenance schedule. All vegetation management activities should take account of the need to maximise biosecurity and prevent the spread of invasive species.

Occasionally sediment will need to be removed (eg once deposits exceed 25 mm in depth). Sediments excavated from a detention basin that receives runoff from residential or standard road and roof areas are generally not toxic or hazardous and can therefore be safely disposed of by either land application or landfilling. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Sediment testing may be required before sediment excavation to determine its classification and appropriate disposal methods. For runoff from busy streets with high vehicle traffic, sediment testing will be essential. In the majority of cases, it will be acceptable to distribute the sediment on-site if there is an appropriate safe and acceptable location to do so. Further detail on waste management is provided in **Chapter 32**. Any damage due to sediment removal or erosion and scour resulting from major events should be repaired and immediately reseeded or planted.

Table 22.1 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required.

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the detention basins should be monitored, and maintenance schedules adjusted to suit requirements. Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

Generic health and safety guidance is provided in **Chapter 36**. CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

Many of the specific maintenance activities for detention basins can be undertaken as part of a general landscape management contract and therefore, if landscape management is already required at site, should have marginal cost implications. If basins are implemented within private property, owners should be educated on their routine maintenance needs, and should understand the long-term Maintenance Plan and any legally binding maintenance agreement.

TABLE 22.1 Operation and maintenance requirements for detention basins

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly
	Cut grass – for spillways and access routes	Monthly (during growing season), or as required
	Cut grass – meadow grass in and around basin	Half yearly (spring – before nesting season, and autumn)
	Manage other vegetation and remove nuisance plants	Monthly (at start, then as required)
	Inspect inlets, outlets and overflows for blockages, and clear if required.	Monthly
	Inspect banksides, structures, pipework etc for evidence of physical damage	Monthly
	Inspect inlets and facility surface for silt accumulation. Establish appropriate silt removal frequencies.	Monthly (for first year), then annually or as required
	Check any penstocks and other mechanical devices	Annually
	Tidy all dead growth before start of growing season	Annually
	Remove sediment from inlets, outlet and forebay	Annually (or as required)
	Manage wetland plants in outlet pool – where provided	Annually (as set out in Chapter 23)
Occasional maintenance	Reseed areas of poor vegetation growth	As required
	Prune and trim any trees and remove cuttings	Every 2 years, or as required
	Remove sediment from inlets, outlets, forebay and main basin when required	Every 5 years, or as required (likely to be minimal requirements where effective upstream source control is provided)
Remedial actions	Repair erosion or other damage by reseeding or re-turfing	As required
	Realignment of rip-rap	As required
	Repair/rehabilitation of inlets, outlets and overflows	As required
	Relevel uneven surfaces and reinstate design levels	As required

22.13 REFERENCE

KENNARD, M F, HOSKINS, C G and FLETCHER, M (1996) *Small embankment reservoirs*, R161, CIRIA, London, UK (ISBN: 978-0-86017-461-5). Go to: **www.ciria.org**

Statutes

Reservoir Act 1975 (c.23)

Health and Safety at Work (etc) Act 1974 (c.37)

Building Act 1984 (c.55)

Flood and Water Management Act 2010 (c.29)

Construction (Design and Management) Regulations (CDM) 2015

23 PONDS AND WETLANDS

Contents

Chapter 23 Ponds and wetlands

This chapter provides guidance on the design of ponds – depressions designed to temporarily store surface water above permanently wet pools that permit settlement of suspended solids and biological removal of pollutants. This includes wetlands, which are ponds with a higher proportion of shallow zones that promote the growth of bottom-rooted plants.

- *Appendix C, Section C.5.4 demonstrates how to design a wetland area for an industrial site.*
- *Appendix C, Section C.5.5 demonstrates how to design a strategic amenity pond.*

23.1 GENERAL DESCRIPTION

Ponds and wetlands are features with a permanent pool of water that provide both attenuation and treatment of surface water runoff. They can support emergent and submerged aquatic vegetation along their shoreline and in shallow, marshy (wetland) zones, which helps enhance treatment processes and has amenity and biodiversity benefits. Dense stands of vegetation facilitate the adhesion of contaminants to vegetation, aerobic decomposition of pollutants and can also help stabilise settled sediment and prevent resuspension. The term "wetland" is used to describe bodies of water with larger proportions of the surface area covered by aquatic planting. They also tend to have greater depth variations and may include shallow islands. However, for the purposes of this document, ponds and wetlands are considered together.

Attenuation storage is provided above the permanent pool and wetland areas. A flow control system at the outfall controls the rates of discharge for a range of water levels, causing the pond volume to fill during storm events. Runoff from each rainfall event is detained and treated in the pool. The volume of the pool influences the effectiveness of the feature in settling out particulate pollutants, with larger volumes providing longer periods of time for sedimentation to occur, and greater opportunities for biodegradation and biological uptake mechanisms.

Ponds and wetlands should always be designed with suitable upstream pre-treatment systems (or separate sediment forebays) in place. This prevents open water features from becoming unsightly and odorous and reduces the risk of rapid silt accumulation, which is generally expensive and difficult to extract and dispose of. Ponds and wetlands perform a valuable function in settling out residual fine silts and in final "polishing" of surface water runoff before discharge.

Well-designed and maintained permanent water bodies can offer important aesthetic, amenity and wildlife benefits to development sites. Ponds can be designed as natural features with shallow, grassed side slopes (**Figure 23.1**) or can be hard landscaped features that complement the character of dense urban environments. Well-managed ponds and wetlands can add significant economic value to a development, increasing property values and attracting business and tourism. Public acceptability of ponds is strongly dependent on their aesthetic quality, on their effective integration within the landscape and on their performance as a community resource, so their form, layout and planting should usually be designed and specified by landscape architects. They should not be designed by engineers without landscape architecture expertise.

Figure 23.1 Soft landscaped pond, Elvetham Heath, Hampshire

Figure 23.2 Hard landscaped planted pond, Springhill, Gloucestershire (courtesy Robert Bray Associates)

Ponds and wetlands can be created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Existing natural water bodies should not be used as a means by which to dispose of surface water runoff where this would create a risk that pollution events, poorer water quality or alternative flow regimes might disturb/damage the natural morphology and/or ecology of the system. There may, however, be scenarios where existing water bodies would benefit from further inputs of cleaned surface water runoff. Locating SuDS ponds and wetlands close to existing ones can also benefit biodiversity.

The design of ponds/wetlands should consider the inclusion of a number of zones:

1. **Sediment forebay (optional) –** Effective pre-treatment (that removes coarse sediments and floating oils) should ideally be implemented via appropriate source control and upstream SuDS Management Train components. Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then the pond can be split to allow coarse sediments to settle in the forebay before the runoff enters the permanent pool. The forebay allows sediment build-up to be easily monitored, and concentrates any required sediment removal activities within a small area, thereby minimising potential damage to the rest of the pond.
2. **Permanent pool** – This is the permanent volume of water that will remain in the pond/wetland throughout the year (less any evaporation and infiltration during extended periods of dry weather). The pool acts as the main treatment zone and helps to protect fine deposited sediments from resuspension. The top water level for this volume should be at the invert level of the outlet structure, unless an "infiltration depth" is included (ie a depth between outlet invert level and top elevation of liner over which infiltration is encouraged to take place). In larger wetlands, this pool volume may be distributed into a number of "micropools".
3. **Attenuation storage volume** – This is the temporary storage volume above the permanent pool that fills as water levels rise during rainfall events, providing the required flow attenuation.
4. **Aquatic bench** – This is the zone of shallow water along the edge of the permanent pool that supports wetland planting, acting as a biological filter and providing ecology, amenity and safety benefits. Where the proportion of planting is increased (ie to create wetland features), there may be other "islands" (zones of shallow, vegetated areas) within the permanent pool.

Where there is a high proportion of shallow water, the extent of water loss by evapotranspiration should be taken into account to ensure that there is likely to be sufficient water supply to sustain good wetland plant growth through the year.

Design features should also include a safe exceedance route, maintenance access to all areas of the pond, a flat safety bench around the perimeter of the pond (to provide a suitable distance before open water (this discourages direct access and facilitates surveillance of the pond and rescue if required) and also usually acts as a maintenance route). Access for maintenance to smaller features may often just be an easement with sufficient space and gradients to allow access by mini excavators.

Figure 23.3 Wetland, Banner Country Park, Upton, Northamptonshire

Larger ponds should, preferably, be divided into zones – providing the water quality and quantity volume storage in a number of independent cells. These can create increased attenuation, longer pollutant removal pathways (and therefore enhanced pollution removal), an easier maintenance regime and more varied ecology. They also allow:

- enhanced biodiversity – with lower zones tending to comprise cleaner water
- a more environmentally effective maintenance programme – through staggered programmes for each of the zones.

Figure 23.4 provides a typical design of a pond in plan view and profile. **Figure 23.5** shows typical planted pond edge details and **Figure 23.6** shows equivalent details for a typical non-planted pond.

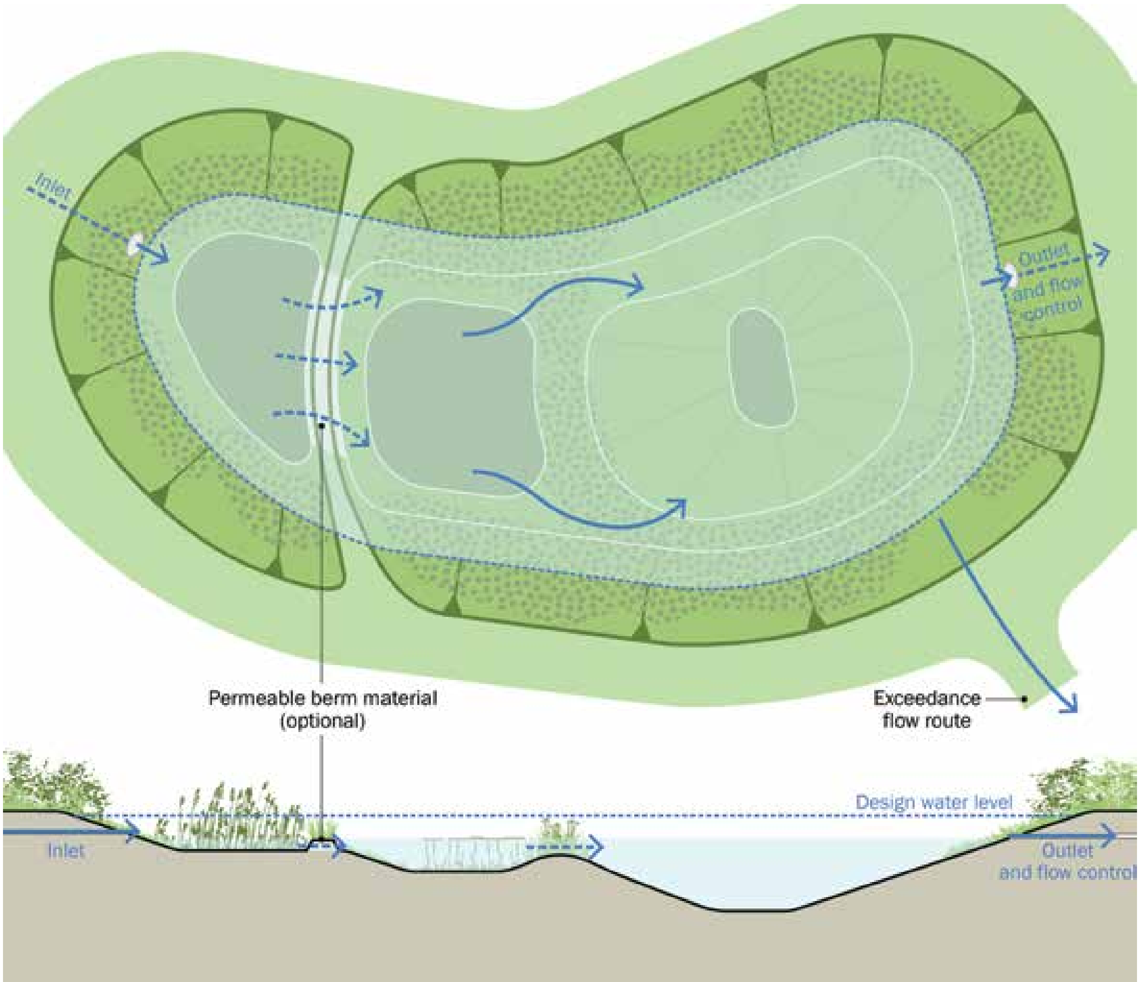

Figure 23.4 Plan view and profile of pond details

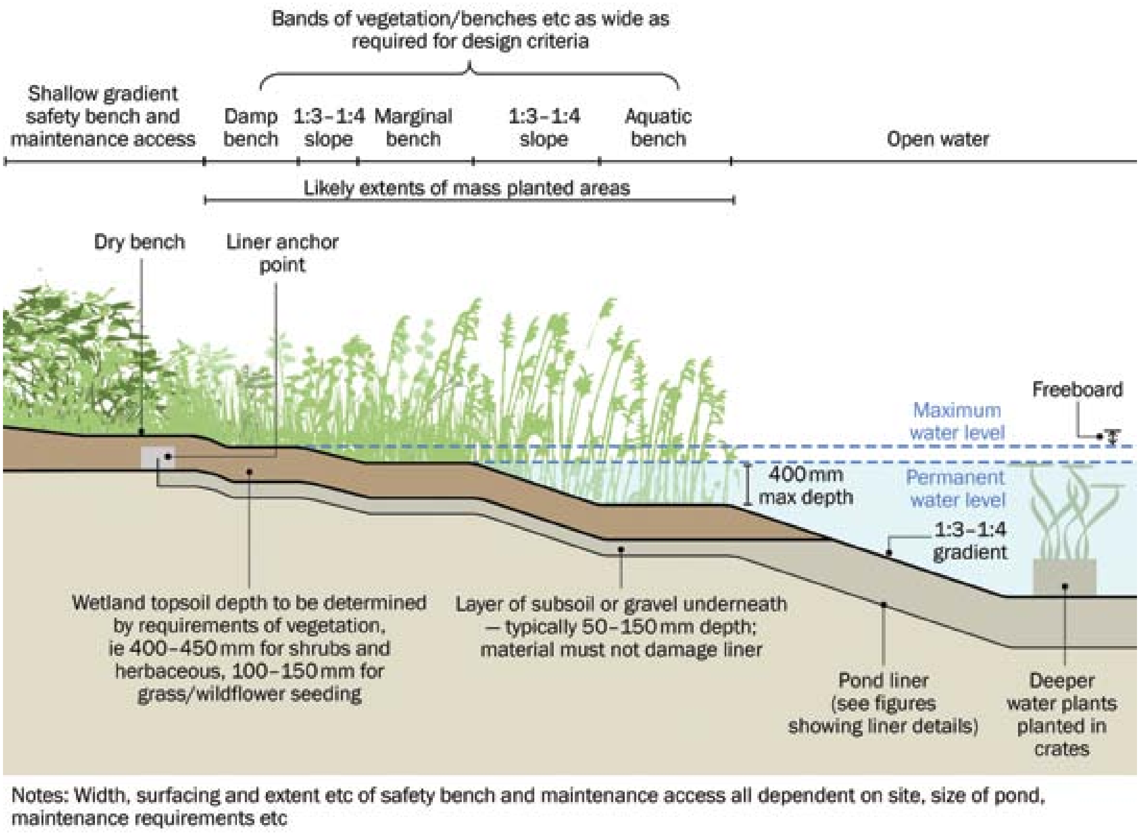

Figure 23.5 Typical planted pond edge details

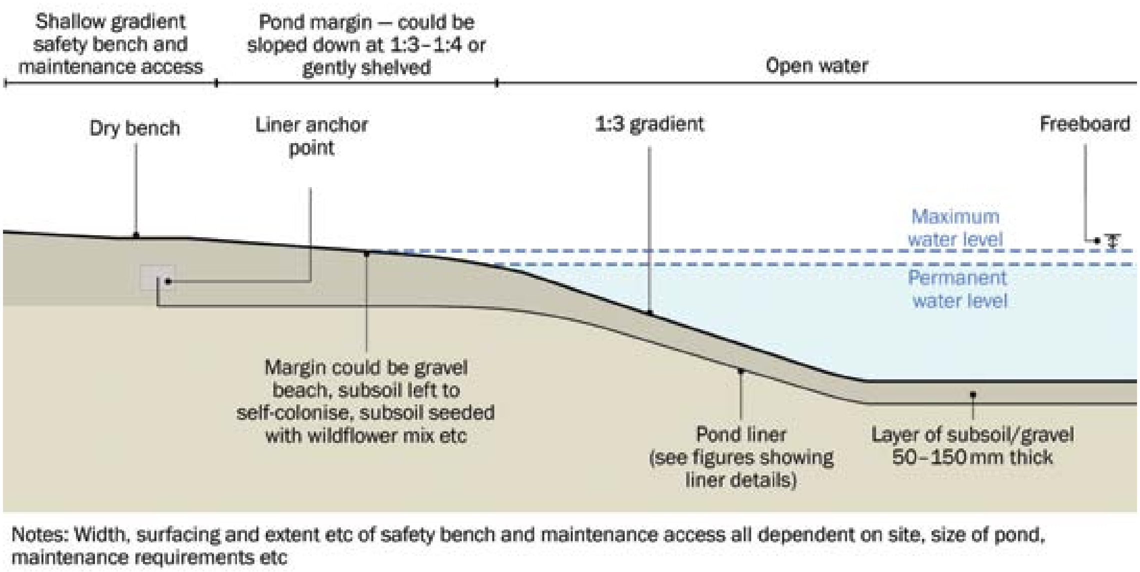

Figure 23.6 Typical non-planted pond edge details

23.2 GENERAL DESIGN CONSIDERATIONS

Ponds should be designed so that flow enters the pond and gradually spreads out, avoiding the creation of dead zones caused by corners, and optimising the sedimentation process through maximising the flow paths. Baffles, pond shaping and islands can be added within the permanent pool to increase the flow path length and maximise water quality treatment effectiveness (**Chapter 28**) (**Figure 23.7**).

Figure 23.7 Pond with baffles and islands, Augustenborg, Sweden

Inlets and outlets should be placed to maximise the flow path through the facility. The ratio of flow path length to width should be at least 3:1 to avoid hydraulic short-circuiting and ideally 4:1 or 5:1. If there are multiple inlets, they should all follow this principle ideally, but as a minimum the length-to-width ratio should be based on the flow-weighted, average flow path length for all inlets.

A balance is required between deep and shallow zones in a pond or wetland. The maximum depth of the permanent pool should not exceed 2 m to avoid stratification and anoxic conditions (and should normally be a maximum of 1.2 m, unless all safety considerations indicate that a greater depth is acceptable). Keeping the permanent water shallow allows oxygen to reach the bottom of the pond, enabling the biodegradation of oils by natural organisms; however, very shallow ponds may be at risk of algal blooms and high biological activity during summer months, and may be at risk of drying out when rainfall is low, therefore some depths of 0.6–1.0 m should usually be included. Greater depths near the outlet will reduce the risk of sediment re-entrainment, and will tend to yield cooler bottom water discharges that may mitigate downstream thermal effects. Deep water supports a relatively few number of plant species compared to shallow zones, so the overall extent of deep water zones should be considered and limited.

The maximum depth of temporary storage above the permanent pool should be limited: 0.5 m is usually appropriate for small to medium-sized ponds, but increased depths may be suitable for larger systems or where the risks can be demonstrated to have been managed appropriately. Surface water wetlands are generally chosen to improve runoff quality, rather than for controlling large volumes of surface water. Where wetlands are used for flow attenuation, the depth of temporary storage above the permanent water level should be such that the risk of plant damage is low.

An aquatic bench should be provided that extends inwards from the normal pond edge and has a maximum depth of 0.4 m below the normal pool water surface elevation. The width can be varied depending on the size of the pond and the extent of vegetation required for safety and aesthetic purposes. On most pond sites, it is important to amend the soil before planting, since ponds are typically placed well below the native soil horizon. In very poor soils nutrient additions should be minimised owing to the risk of algal blooms and eutrophication.

Any pond embankment should be designed in accordance with best practice, as described in Kennard *et al* (1996). Designs should meet all requirements of the Reservoir Act 1975 as amended by the Flood and Water Management Act 2010. Even if the impounded pond does not come within the thresholds of the Reservoirs Act, owners still have statutory duties for the safety of others under legislation such as the Health and Safety at Work (etc) Act 1974 and the Building Act 1984. Consideration should be given to the safe routing of floodwater when the design event is exceeded, and to mitigating the risks of potential embankment failure.

Safety benches and maintenance access routes should be provided at an appropriate level above the permanent pond. A suitable width for a safety bench is 3.5 m, with a slope of less than 1 in 15, although this will depend on land availability, designated access and the type of maintenance equipment required for the pond. Side slopes to the pond between the aquatic and safety bench should not usually exceed 1 in 3 for public safety reasons, and wherever mowing is required, slopes should preferably be no steeper than 1 in 4. Where ponds are designed to be created as hard landscape features within dense urban areas, acceptable slopes and depths should be developed by the designer, giving full consideration to the management of health and safety (**Chapter 36**). Vertical side slopes may be appropriate in such scenarios, provided depths are kept shallow, the system is well integrated within the urban landscape and wildlife needs are fully taken into account.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

Figure 23.8 Approach to managing risks associated with a steep-sided pond that also adds amenity value, Upton, Northamptonshire (courtesy Peterborough City Council)

23.3 SELECTION AND SITING OF PONDS OR WETLANDS

Ponds or wetlands are generally suitable for most types of new development and redevelopment, and can be used in both residential and non-residential areas. Ponds are also appropriate for use in retrofit situations where land is available at a suitable point near the outlet of the drainage system.

Through the effective use of upstream source control measures, SuDS ponds can usually be designed as small features that blend unobtrusively into the landscape. Large bodies of open water need very careful consideration. Ponds and wetlands can usually be integrated to the contours of a site fairly easily and the potential variation in their design form and aesthetics means that they can complement and enhance a wide range of urban settings. Ponds and wetlands should be placed in developments so they are overlooked by housing and not hidden in an unseen corner. Alternatively, they can be located in larger areas of open space. This ensures that the water features are a valued part of a development.

It may be difficult to site a pond on steeply sloping sites, and ponds should not be sited on unstable ground. Ground stability should be verified by assessing site soil and groundwater conditions. Ponds should not be built on waste-fill materials, uncontrolled fill or non-engineered fill. Where practical the pond length should be oriented along the direction of prevailing summer winds to enhance wind mixing.

The soil below a wet pond should be sufficiently impermeable to maintain the water levels within the permanent pool at the required level. In permeable strata, a liner (or other impermeable material such as puddled clay) will be required to prevent the pond drying out. Evaluation of soils should be based on soils investigations and permeability tests.

In areas containing contaminated soils or contaminated groundwater (brownfield sites), ponds can be used, providing the system is fully sealed, preventing exchange of water between pond and groundwater. Any excavation or earthmoving processes required should be assessed to ensure that mobilisation of contamination does not occur.

If used on a site with a sensitive underlying groundwater zone, or if used to treat runoff from a potential pollution hotspot, a hydrogeological risk assessment will generally be required to determine an appropriate separation distance between the bottom of the pond and the elevation of the annual maximum water table unless a liner is proposed. If the subsurface soils are at all permeable, a liner (or other impermeable material such as puddle clay) will be required to prevent leakage.

Where the groundwater table is close to the base of the pond, hydraulic connectivity between the water in the pond and the groundwater should be prevented, unless the water quality requirements for infiltration have been met (**Chapter 4**). Also, the operation of the outfall should be confirmed for the annual maximum water table level. The maximum expected groundwater level should always be beneath the temporary detention zone.

Ponds and wetlands are not appropriate management measures for runoff from construction sites or for the construction period of the development, when sediment loadings are likely to be very high.

23.4 HYDRAULIC DESIGN

23.4.1 General

Guidance on hydraulic criteria and design standards is given in **Chapter 3** and methods for sizing storage are presented in **Chapter 24**. The pond/wetland temporary storage volume should be sized to provide flood attenuation for all events to meet the site standards of service – up to the 10, 30 or 100/200 year events (including appropriate climate change and urban creep allowances), if required, with discharges being constrained to the equivalent greenfield (or other agreed) rates. Consideration should be given to larger events, as these should be safely routed downstream. Attenuation volumes may need to be increased if additional storage is required to deliver adequate volumetric control of runoff for the 100 year event (**Section 23.4.4**).

23.4.2 Interception design

Where infiltration is designed to occur when the water level rises above the level of the permanent pool, then some contribution to Interception delivery (the prevention of runoff for small rainfall events) may be achieved. The extent of any volumetric reduction achieved in this way is likely to be very limited and requires careful assessment and design.

23.4.3 Peak flow control design

Ponds or wetlands can help reduce flow rates from a site by controlling the discharge rate and allowing the temporary storage volume to fill during storm events. The required peak flow control and storage volume can be determined using standard hydraulic assessment (**Chapter 24**).

23.4.4 Volume control design

Ponds and wetlands do not normally contribute to volumetric control of runoff, but they can be used to deliver further attenuation where Long-Term Storage is not practical (**Chapter 3**). Assessment of volumetric control should follow the normal hydraulic assessment methods in **Chapter 24**.

23.4.5 Exceedance flow design

An exceedance flow route will be required for rainfall events that exceed the design capacity of the pond or wetland and to convey flows should outlet blockages occur. This can be achieved by installing an overflow pipe or weir/overflow/spillway structure above the design water storage level to convey excess flows downstream. They should be designed to prevent over-topping of any embankment which might cause structural damage, and spillways should be located so that downstream people and property are not put at risk. For small ponds, a simple grass channel integrated into the landscape is usually suitable as an exceedance route. A freeboard of 300 mm for the design event is usually sufficient for larger ponds, but where risks are particularly high a further allowance should be agreed with the environmental regulator or other authority. Conversely, for smaller ponds, there may be no need for a freeboard, provided the risk to people and property has been evaluated.

The exceedance flow capacity of the overflow should be confirmed using normal hydraulic assessment methods and analyses (weir, orifice and pipe flow). Exceedance flow paths beyond the capacity of the overflow should also be confirmed.

Any exceedance flow structure should be located as close to the inlet as possible to minimise the flow path length for above-capacity flows (thus reducing the risk of scouring). See **Section 23.8.2** on outlet design for details. The overflow should not impede access to any inlet or outlet structure that manages more frequent flows.

23.5 TREATMENT DESIGN

Ponds and wetlands will not provide a significant reduction in contaminant load via volumetric runoff control, as they generally do not provide Interception (**Section 23.4.2**).

Ponds and wetlands treat incoming runoff through settling and biological uptake. The primary pollutant removal mechanism is the settling of silts and suspended sediments. Uptake of pollutants, particularly nutrients, also occurs to some degree through the biological activity of the pond. Emergent and submerged aquatic vegetation along the shoreline support an active microbial community capable of consuming dissolved constituents in the inflow. Pond inflows from most runoff events replace a portion of the prior volume and are stored and treated until displaced by the perennial baseflow or next runoff event.

The primary design factor that determines a pond's treatment efficiency is the volume of the permanent pool. Research findings from Lampe *et al* (2003) suggests that permanent pond sizes > 2 × the mean annual storm volume do not significantly enhance treatment performance or reduce outfall concentration variability. This equates a treatment volume of 10–15 mm of rainfall depth falling over the contributing catchment, or around 1–1.5 times the V_t formula defined for Scotland as shown in **Equation 23.1**.

EQ. 23.1 Water quality treatment volume calculation using variable rainfall depths (for Scotland)

$$V_t = 9D\left[\frac{SOIL}{2} + I\left(1 - \frac{SOIL}{2}\right)\right]$$

where:

V_t	=	water quality treatment volume (as a function of the total development area) (m^3/ha)
SOIL	=	soil classification (from Flood Studies or Wallingford Procedure WRAP map)
I	=	fraction of the area that is impervious (eg 30% impermeable area = 0.3)
D	=	M5-60 minute rainfall depth (ie 5-year return period, 60 minute duration storm depth determined from the Wallingford Procedure)

Where ponds are implemented as final polishing elements downstream of components that deliver both sediment removal and further treatment (eg permeable pavements, swales or bioretention systems), then smaller sizes may be acceptable, depending on the effectiveness of the upstream SuDS components. Larger ponds should not be considered as providing enhanced treatment capacity, and ponds should not accept contaminated runoff directly, as this will cause failure in delivering amenity and biodiversity performance and will increase maintenance risks and costs.

In general, wet pond facilities function best when surface water entering the pond moves through the pond as a single wave or unit, fully displacing the wet pond volume – a phenomena known as plug flow. By preventing short-circuiting occurring, this flow pattern maximises the hydraulic retention time, which enhances particulate and particle-bound sediment settlement – a key process in pond treatment effectiveness. Water quality event storage can be provided in multiple cells. Treatment performance is enhanced when multiple treatment pathways are provided using multiple cells, longer flowpaths, higher surface area-to-volume ratios and complex microtopography.

Evidence of the pollutant removal efficiencies of ponds and wetlands is presented in **Chapter 26, Annex 3**.

For proper functioning and to prevent sediment and associated pollutants from eroding and flushing out of ponds during storms, it is important that the permanent pond is retained. This may mean that an impermeable liner is required to prevent leakage from the pond.

If ponds have to be > 1.5 m in depth, it is recommended that some form of recirculation be provided in the summer, such as a fountain or aerator, to prevent stagnation and low dissolved oxygen conditions. A small amount of base flow may be desirable to maintain circulation and reduce the potential for low oxygen conditions during late summer.

Trees along the west and south sides of ponds (not on embankments) can be used to reduce the risk of thermal heating, particularly in dense urban areas where urban heat island effects may drive temperatures particularly high during summer months. As well as giving shade, trees and shrubs also discourage waterfowl use and the attendant phosphorous enrichment problems they cause. Trees should be set back so that the branches will not extend over the pond.

23.6 AMENITY DESIGN

Pond and wetland design should add value to the amenity of the local communities and be of an appropriate scale and form to suit the surrounding landscape character. In green open spaces, it is likely that they would have a natural appearance with soft edges and forms that blend with the surrounding area. In dense urban environments, hard straight edges may be more suitable, provided that wildlife access is considered.

The extent to which the pond is designed as an amenity feature will depend on the likely level of contamination of the inflows. Where it is being used as a final polishing component, amenity potential will be high.

Ponds can provide an educational resource for local schools and community environment groups and be the focal point of a recreational area (**Figures 23.9** and **23.10**).

Figure 23.9 Pond dipping platform, Matchborough First School, Worcestershire (courtesy Robert Bray Associates)

Figure 23.10 Urban pond, Western Harbour, Malmö, Sweden (courtesy Essex County Council)

Pond design should be undertaken with appropriate inputs from engineers, hydrologists, ecologists and landscape architects. Designs should take account of the local landscape character and environment and community requirements (**Chapter 34**), as well as the biodiversity objectives for the site.

High fencing tends to isolate pond systems, reduces amenity benefits and potentially increases health and safety risks. Toddler-proof fencing, if thought necessary, combined with effective planting and landscaping can be used to manage public access points and facilitate the movement of wildlife. Pedestrian access to shallow pool areas that are enhanced with emergent wetland vegetation can allow the pond to be more accessible without incurring safety risks. If fences are deemed necessary, consideration should be given to checking the suitability of a pond at the site. If fences have to be used, it is better to set them well back from the edge of the pond so that they do not reinforce negative perceptions of water in the environment.

Picnic tables or seating for local residents or visitors can be installed on flat areas overlooking or adjoining the pond, and walking or jogging trails around the pond are also often easily integrated into site design. Visual aesthetics can often be enhanced with clusters of trees and shrubs rather than using individual plants. Trees should be set back from the water's edge so that branches do not extend over the pond (to prevent leaf drop into the water and too much shading).

Children should not be able to gain access to spillways, and all vertical drops exceeding 1.2 m (eg headwalls above pipe inlets/outfalls) should be avoided (or if necessary fenced). Wherever possible, vertical drops should be avoided or graded to shallow slopes unless health and safety risk assessment confirms their acceptability.

For large ponds, consideration should be given to whether fishing in the water is appropriate and, if not, warning signs should be considered. Life-saving equipment or signs highlighting the risks associated with entering the water should only be provided where required by the risk assessment, and operators will have to inspect any signage or equipment on a regular basis to minimise any liability risks.

▶ Health and safety risk management principles are presented in **Chapter 36**.

Interpretation boards can be provided to inform the public of the function of the pond, and also to provide information on the local flora and fauna that the system supports.

▶ **Chapter 34** discusses public education and awareness-raising strategies.

23.7 BIODIVERSITY DESIGN

Wherever possible, ponds and wetlands should be located in, or adjacent to, non-intensively managed landscapes where natural sources of native species are likely to be good and/or should aim to provide connectivity to other ecological networks. Surrounding habitat should provide a variety of both covered and open approaches to the water which are favoured by differing species.

Ponds should have varying depths (which will provide a range of different habitats) and should, where appropriate, include deep (1 m) over-wintering areas as refuges for wildlife during severe winters. The development of mosaics of marginal plants should be encouraged (rather than single-species stands) to maximise habitat structural diversity. The development of open and lightly shaded areas or pools should also be encouraged, as this will add to the diversity of habitats available.

Wherever possible, ponds or wetlands should be located away from artificial light sources, as this will reduce the value of the feature to foraging bats. Similarly, new lighting features should be avoided in close proximity to ponds.

Figure 23.11 Balancing pond with marginal wetland treatment zone, Hopwood Park motorway services, M42, Worcestershire

Ponds and wetlands should be designed to prevent/discourage the introduction of species such as fish and wildfowl, where an objective of the system is to support amphibians, particularly great crested newts. If the pond discharges to a nutrient sensitive receptor, dense planting can be considered on the side slopes to discourage wildfowl use. Conversely, where wildfowl use is to be encouraged, "bays" suitable for breeding birds can be integrated into the shape of larger ponds and breeding "islands" should be no closer than 3 m from the edge of the pond to prevent access by foxes.

Pond designs can be improved for ecology by developing the pond system in two phases: Phase 1 establishes the basic shape and structure of the pond with a follow-up Phase 2 (1–2 years later) to undertake fine-tuning of the scheme. Examples of small-scale refinement that can be incorporated in Phase 2 and that add considerably to the habitat value of sites include:

- addition of small-scale topographic features (eg reprofiling of pond margins to increase the extent of seasonal water level variations
- maximising the potential of unplanned habitats that occur on most sites, such as runoff from grassed slopes and natural seepages.

Ecological value can be further enhanced by creating small pools around the margins of larger ponds, which are fed by clean surface runoff from non-intensively managed grassland, scrub or woodland on the basin sides. These pools should be located above the level of the main SuDS pond. If some ponds, or parts of basins, are not exposed to the main pollutant burden, this may allow a wider range of animals and plants to exploit some parts of the site. As well as enhancing biodiversity, such a design approach should ensure rapid re-colonisation following any potential spill event. This type of benefit may also be achieved through the use of multiple ponds in series, where water quality improves through the train.

In contaminated systems, shallow water and wetland areas can support a range of wildlife that is less vulnerable to the effects of pollutants than submerged aquatic plants and those animals that live permanently under the water (such as mayfly larvae, dragonfly larvae and fish). Further information on maximising the ecological benefits of SuDS is given in Biggs (2003) and Graham *et al* (2013).

23.8 PHYSICAL SPECIFICATIONS

23.8.1 Pre-treatment and inlets

The number of inlets to the feature should be limited, preferably to one. The flowpath length should be maximised from inlet to outlet for all inlets.

Effective pre-treatment for all inlets should ideally be implemented via appropriate source control and upstream SuDS Management Train components (**Chapter 4**). As many contaminants adhere to sediment, its removal will ensure that the water in the main pool is relatively clean and can deliver on amenity and biodiversity objectives. Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then the pond/wetland area can be split to allow heavier sediments to drop out of suspension before the runoff enters the main body of the system. The sediment forebay allows sediment build-up to be easily monitored, and concentrates any required sediment removal activities within a small area, thereby minimising potential damage to the rest of the pond or wetland. The plan area of the sedimentation bay should be at least 10% of the total basin area and could consist of a separate basin or be formed by building an earth berm, stone- or rock-filled gabion or rip-rap across the upstream portion of the basin. For systems with multiple inlets, pre-treatment should be provided for each inlet that is likely to contribute a significant sediment load. Each forebay should be accessible and easily maintained.

Consideration should be given to installing a fixed sediment depth marker in forebays where high sediment loads are expected, to measure sediment deposition with time. This will assist with the development of appropriate future maintenance schedules. The base of the forebay can be reinforced to facilitate sediment removal. If a membrane liner is used without protection, great care should be taken during sediment removal operations.

The energy of the incoming flows should be dissipated to minimise the risk of scouring and erosion, and to prevent disturbance to the permanent pool volume. This can be achieved by stabilising inflow channels using rip-rap or other erosion control systems, or by partially or fully submerging the inlet pipe. The scale of the erosion mitigation system should be physically and aesthetically proportionate to the size of the pond.

Figure 23.12 Energy dissipating inlet channels for ponds, Augustenborg, Sweden (courtesy Graham Fairhurst and Illman Young)

Safety grilles may be required if inlet pipe diameters allow public entry, but they tend to increase the risks of blockage and can present a hazard in themselves so, wherever possible, inlet infrastructure should be designed so that they are not required.

If the pond or wetland is to be constructed off-line, as a treatment facility only, then an upstream bypass structure can be used to divert events that require treatment into the pond/wetland. Flows exceeding this will then bypass the system, reducing the potential for turbulence and mixing, and allowing optimum contaminant removal processes to occur.

▶ Guidance on inlet design is set out in **Chapter 28**.

23.8.2 Outlets

At the outlet, there will normally be a requirement for some form of flow control system. A manhole-type outlet structure can accommodate a variety of outlet control mechanisms. Ponds and wetlands will generally require a non-clogging, variable flow rate control structure at the outlet, together with an emergency overflow. Low flow controls are generally provided via protected orifices, which can then be combined with overflow channels and overflow weir sections and/or culverts for larger events. Multiple orifices or pipe outlets can be used to achieve the same objectives. Trash screens are not recommended, but where they are considered necessary to prevent access into pipework, they should be designed so that debris does not unduly obstruct or reduce design flow rates.

▶ The design of exceedance flow management components is discussed in **Section 23.4.5**.

The outlet area should be the deepest point to provide final settling and to prevent resuspension of sediments. Energy dissipation may be required downstream of the outlet to prevent scouring and erosion – but this will depend on the outflow discharge rates, the outfall design and the vulnerability of the receiving watercourse or lake to erosion.

For outlet pipes through embankments, seepage control in the form of collars may need to be provided.

▶ Guidance on outlet design is set out in **Chapter 28**.

23.9 MATERIALS

23.9.1 Pond/wetland liners

Pond liners can be formed from a range of different materials. The requirements for benching should always be considered, to ensure that layers of saturated subsoil do not slip off the liner, otherwise soil containment systems can be used. Geosynthetic clay liners (**Figure 23.13**) tend to be less prone to stability issues because the material is a sandwich of bentonite between two geotextiles, but the stability of overlying soil layers should still be a consideration.

Geomembrane liners (butyl is a common form) should normally be protected with geotextile fleece layers (**Figure 23.14**). Clay liners should be protected from drying out (**Figure 23.15**). The thickness of clay required to ensure complete impermeability should be at least 500 mm, and preferably 1 m. The minimum permeability of the compacted clay should be 1×10^{-9} m/s.

Appropriate specifications for geomembranes are presented in **Section 30.5**.

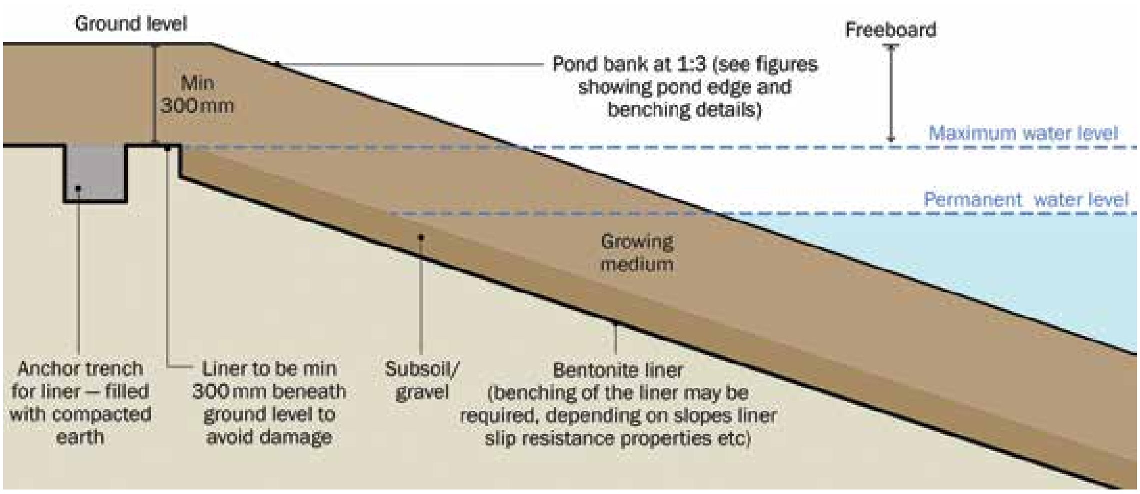

Figure 23.13 Details for a typical geosynthetic liner

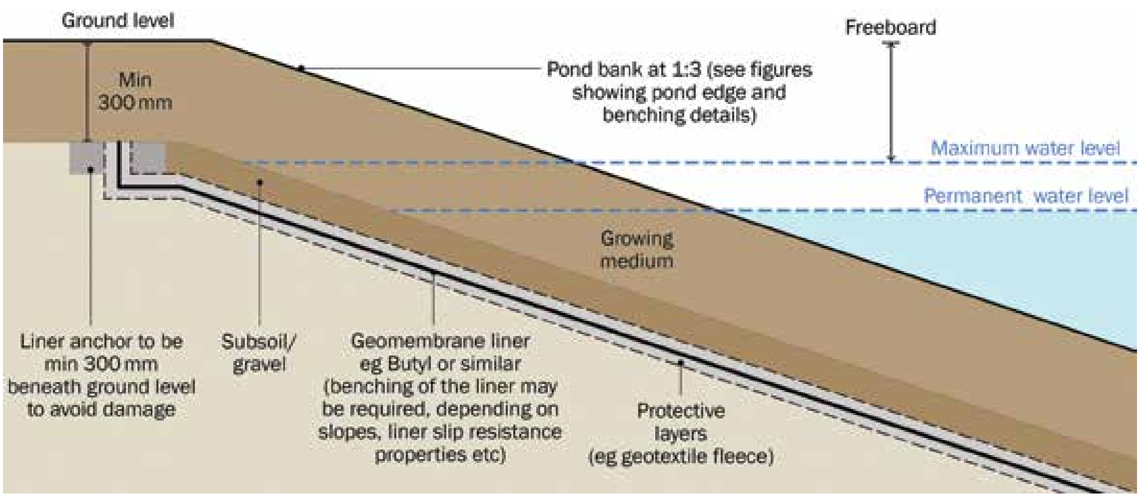

Figure 23.14 Details for a typical geomembrane liner

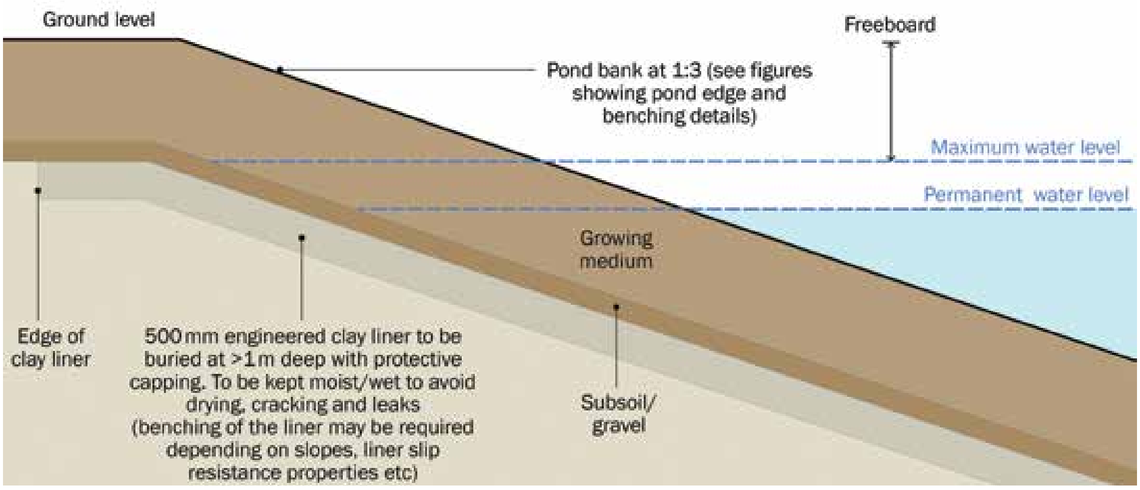

Figure 23.15 Details for a typical clay liner

23.9.2 Embankment fill material

If an embankment is required to impound the water, the embankment fill material should use inert natural soils that will not leach contaminants into the stored runoff. Embankments should be designed to be stable and watertight, and the detailed guidance contained within Kennard *et al* (1996) should be followed.

23.9.3 Subsoil and topsoil

Appropriate specifications for subsoils and topsoils are presented in **Section 30.4**.

23.10 LANDSCAPE DESIGN AND PLANTING

In green open space and natural landscaped areas, ponds should be developed to mimic natural forms, using soft geometries with curved boundaries and undulating margins. In hard landscaped, urban areas, a more functional and linear structure may be appropriate.

Figure 23.16 Geometric design of pond in an urban area, Malmö, Sweden (courtesy Illman Young)

Vegetation can enhance the appearance of the pond, stabilise side slopes and prevent erosion, serve as wildlife habitat and temporarily conceal unsightly litter and debris. Aquatic vegetation provides some nutrient uptake, stabilises the sediments in the base of the facility (thus preventing scour and resuspension during heavy storms) and increases sediment settling effectiveness by slowing the flows across the pond. A vegetated aquatic bench can help prevent children from entering open-water areas and discourage the use of adjacent grassed areas by geese. Plants should therefore be encouraged along the aquatic bench, the safety bench and side slopes and within shallow areas of the pool itself. Some areas should be left open for wildlife access and to allow clear sightlines favoured by certain species.

Where possible, wetland plants should be encouraged in pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes (emergent wetlands) or within shallow areas of the pond itself. The best elevations for establishing wetland plants, either through transplantation or volunteer colonisation, are within 150 mm of the normal pool. Tall, emergent species should be planted on aquatic benches, although the selection of species should also consider the risks of children not being observed if they get into difficulties due to being hidden by vegetation. The plants should not restrict visibility of the water's edge or hinder adult supervision, particularly in amenity areas. Dense planting of marginal floating-leaved and aquatic plants should be avoided, and the wetland should be left to colonise as naturally as possible. Over-planting initially will tend to fill space that could otherwise be exploited by self-colonising local species, and so reduces the potential ecological value of the wetland. A diversity of plants is very valuable ecologically, and monocultures of, for example, reeds should be avoided. Wetland plants should be tolerant of fluctuating water levels. Ideal species are those that offer a high density of stems in the submerged zone, maximising the contact between water and the surface on which microorganisms grow, while providing uniform flow conditions.

Designers should develop an appropriate plant list (usually comprising species found within 30 km of the development site), which may vary, depending on the design and landscape objectives for the scheme.

Non-native species are more likely to be appropriate in more formal or urban settings, but may also be beneficial in enhancing pollinators and in providing aesthetic value. Particular care should be taken not to introduce invasive species to the pond or wetland system, and all plant supplies should be accredited or plant sources known. Were appropriate, the species mix should aim to create habitats that contribute to local, regional and national biodiversity strategies (**Chapter 29**).

Wetland planting density varies but is typically 4–8 plants per m^2. Wetland planting should take place between early April and mid June so that the plants have a full growing season to develop the root reserves they need to survive the winter. Vegetation usually needs to be quickly established once surface water flows are introduced to the system, in order to ensure pollutant removal levels and to reduce the risk of bankside erosion. Some ponds at the end of a drainage system may lend themselves to natural colonisation, particularly if linking to existing wetlands or watercourses. The slow colonisation of these ponds can provide valuable successional habitats. However, erosion during establishment of the vegetation needs to be carefully considered.

The soils of a pond buffer are often severely compacted during the construction process. The density of these compacted soils is so great that it effectively prevents root penetration, and therefore may lead to premature mortality or loss of vigour. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and then backfill these with uncompacted topsoil. Where ponds and wetlands have been excavated to subsoils that lack the nutrients and organic matter to support quality growth, topsoil or wetland mulch should be added to all planting areas – taking account of the need to control ongoing nutrient loadings to the water body. A soil depth of 150 mm is usually adequate for grassed areas, but up to 450 mm may be required to support large shrubs.

Herne Bay, Kent (courtesy Kent County Council)

Dundee City Council Social Work Department (courtesy Abertay University)

Figure 23.17 Examples of different types of planting

23.11 CONSTRUCTION REQUIREMENTS

The bottom and side slopes of the pond, including any benches, should be carefully prepared to ensure that they are structurally sound. Any embankments should be checked to ensure that they meet their design criteria. The preparation should also ensure that the basin will satisfactorily retain the surface water runoff without significant erosion damage.

Backfilling against inlet and outlet structures needs to be controlled so as to minimise settlement and erosion. The soils used to finish the side slopes of the pond above the retained level need to be suitably fertile, porous and of sufficient depth to ensure healthy vegetation growth. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

There are various materials available to help prevent erosion while allowing plants to establish (**Section 29.4.3**). Ideally, planting would be planned over a number of years so that the rate of establishment can be monitored and densities adjusted accordingly.

Ponds can only be used to manage construction runoff where there is provision made for their complete rehabilitation to original design formation levels before handover. Planting schemes should be delayed until full rehabilitation has been undertaken.

Further detail on construction activities and the programming of construction activities is provided in **Chapter 31**. Generic health and safety guidance is provided in **Chapter 36**. A construction phase health and safety plan is required under CDM 2015. This should ensure that all construction risks have been identified, eliminated, reduced and/or controlled where appropriate.

23.12 OPERATION AND MAINTENANCE REQUIREMENTS

Ponds and wetlands will require regular maintenance to ensure continuing operation to design performance standards, and all designers should provide detailed specifications and frequencies for the required maintenance activities, along with likely machinery requirements and typical annual costs – within the Maintenance Plan. The treatment performance of ponds and wetlands is dependent on maintenance, and robust management plans will be required to ensure maintenance is carried out in the long term. Different designs will have different operation and maintenance requirements, but this section gives some generic guidance.

Maintenance of ponds is relatively straightforward for landscape contractors, and typically there should only be a small amount of extra work required for a SuDS pond or wetland feature over and above what is necessary for standard public open space.

Regular inspection and maintenance is important for the effective operation of ponds as designed. Maintenance responsibility for a pond and its surrounding area should always be placed with a responsible organisation. Litter and debris removal should be undertaken as part of general landscape maintenance for the site and before any other SuDS management task. All litter should be removed from site.

Any invasive maintenance work such as silt or vegetation removal is only required intermittently, but it should be planned to be sympathetic to the requirements of wildlife in a pond. Care should be taken to avoid disturbance to nesting birds during the breeding season and habitats of target species (eg great crested newt and water voles) at critical times. The window for carrying out maintenance to achieve this is usually towards the end of the growing season (typically September/October), although this will vary with species). Invasive silt and vegetation removal should only be carried out to limited areas at any one time (25–30% of the pond area on one occasion each year to minimise the impact on biodiversity. Plant management, to achieve particular desired habitat effects, should be clearly specified in a maintenance schedule.

Site vegetation should be trimmed as necessary to keep the pond free of leaves and to maintain the aesthetic appearance of the site. Slope areas that have become bare should be re-vegetated and any eroded areas should be regraded before replanting.

Maintenance access (or "easement") should be provided to the pond from a public or private road. An assessment should be made at the planning stage regarding the maintenance and associated access requirements. Ideally, access should be at least 3.5 m wide, have a maximum cross fall of 1 in 7, and be sufficiently robust to withstand maintenance equipment and vehicles. However, temporary access routes for infrequent operations could be considered where permanent routes are not appropriate. The access should extend to any forebay, safety and aquatic benches, inlet and outlet infrastructure. Consideration should be given as to whether maintenance vehicles will need to turn around. Wherever possible SuDS ponds and wetlands should be designed so that special machinery is not required to undertake maintenance.

Table 23.1 provides guidance on the type of operational and maintenance requirements that may be appropriate. The list of actions is not exhaustive and some actions may not always be required. Consideration should be given to the need to control risks to biosecurity during maintenance operations and guidance is provided in **Chapter 29**.

Sediments excavated from ponds or forebays that receive runoff from residential or standard road and roof areas should be safely disposed of in accordance with current waste management legislation. However, consultation should take place with the environmental regulator to confirm appropriate protocols. Chemical testing of the sediment may be required, before sediment excavation, to determine its classification and appropriate disposal methods. For industrial site runoff, sediment testing will be essential. In the majority of cases on low-risk sites with source control and a Management Train, it will be acceptable to distribute the sediment on site, if there is an appropriate safe and acceptable location to do so. Further detail on waste management is provided in **Chapter 33**. If ponds are to be drawn down, care should be taken to prevent downstream discharge of sediments and anoxic water. The environmental regulator should be notified before such activities.

New ponds may become rapidly dominated by invasive native plants, particularly common bulrush (Typha latifolia). As it is not desirable for all new ponds to be bulrush dominated, it should be ensured that in the first five years, while vegetation is establishing, certain plant growth is controlled. After this time, ponds can usually be allowed to develop naturally recognising that, unless the margins are occasionally managed, they are likely to become dominated by trees and shrubs.

Eutrophication of SuDS ponds can occur during the summer months. This is best alleviated by controlling the nutrient source or providing a continuous baseflow to the pond. Unless eutrophication is severe, aeration can be used as a stop-gap measure to save aquatic animal species and reduce risks to receiving waters. However, the addition of barley straw bales, dredging or rendering the nutrients inactive by chemical means can also be successful.

Maintenance Plans and schedules should be developed during the design phase. Specific maintenance needs of the pond should be monitored, and maintenance schedules adjusted to suit requirements. Further detail on the preparation of maintenance specifications and schedules of work is given in **Chapter 32**.

Generic health and safety guidance is provided in **Chapter 36**. CDM 2015 requires designers to ensure that all maintenance risks have been identified, eliminated, reduced and/or controlled where appropriate. This information will be required as part of the health and safety file.

TABLE 23.1 **Operation and maintenance requirements for ponds and wetlands**

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Remove litter and debris	Monthly (or as required)
	Cut the grass – public areas	Monthly (during growing season)
	Cut the meadow grass	Half yearly (spring, before nesting season, and autumn)
	Inspect marginal and bankside vegetation and remove nuisance plants (for first 3 years)	Monthly (at start, then as required)
	Inspect inlets, outlets, banksides, structures, pipework etc for evidence of blockage and/or physical damage	Monthly
	Inspect water body for signs of poor water quality	Monthly (May – October)
	Inspect silt accumulation rates in any forebay and in main body of the pond and establish appropriate removal frequencies; undertake contamination testing once some build-up has occurred, to inform management and disposal options	Half yearly
	Check any mechanical devices, eg penstocks	Half yearly
	Hand cut submerged and emergent aquatic plants (at minimum of 0.1 m above pond base; include max 25% of pond surface)	Annually
	Remove 25% of bank vegetation from water's edge to a minimum of 1 m above water level	Annually
	Tidy all dead growth (scrub clearance) before start of growing season (Note: tree maintenance is usually part of overall landscape management contract)	Annually
	Remove sediment from any forebay.	Every 1–5 years, or as required
	Remove sediment and planting from one quadrant of the main body of ponds without sediment forebays.	Every 5 years, or as required
Occasional maintenance	Remove sediment from the main body of big ponds when pool volume is reduced by 20%	With effective pre-treatment, this will only be required rarely, eg every 25–50 years
Remedial actions	Repair erosion or other damage	As required
	Replant, where necessary	As required
	Aerate pond when signs of eutrophication are detected	As required
	Realign rip-rap or repair other damage	As required
	Repair / rehabilitate inlets, outlets and overflows.	As required

23.13 REFERENCES

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Building Act 1984 (c.55)

Flood and Water Management Act 2010 (c.29)

Construction (Design and Management) Regulations (CDM) 2015

Everyone with an interest in SuDS

Those responsible for policy or decision making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

E

Audience:
Those responsible for delivering and managing a SuDS scheme

Supporting guidance

Image courtesy Kent County Council

24 HYDROLOGY AND HYDRAULICS: DESIGN METHODS AND CALCULATIONS

Contents

Chapter 24

Hydrology and hydraulics: design methods and calculations

This chapter presents the design methods and tools required to size storage and conveyance systems to meet the water quantity design criteria and good practice design standards. This includes how to estimate runoff for the greenfield or previously developed site.

- *Water quantity design criteria are set out in Chapter 3.*
- *Guidance on the SuDS design process is provided in Chapter 7, with an overview of the process for sizing storage and conveyance system components presented in Figure 7.12.*
- *Guidance on component sizing for water quantity and water quality management is provided in Chapters 11–23.*
- *Chapter 26 covers assessing the suitability of using infiltration to dispose of surface water runoff, testing and infiltration design methods.*
- *Chapter 26 provides guidance on design methods for water quality management.*

24.1 INTRODUCTION

The preliminary calculations required to design a SuDS scheme to meet the hydraulic design criteria are:

1. **for greenfield and previously developed sites:** an estimate of the peak runoff rates and runoff volumes from the site in its greenfield state
2. **for previously developed sites:** an estimate of the peak runoff rates and volumes from the site in its previously developed state

   These runoff rates will dictate the rate to which the runoff from the site should be controlled (as required by water quantity standard 2); and the calculation methods are set out in **Sections 24.3 and 24.5**.

   These runoff volumes will dictate the allowable volume of runoff that can be discharged from the site (as required by water quantity standard 1); and the calculation methods are set out in **Sections 24.4 and 24.5**.
3. **for the proposed development:** an estimate of the runoff rates and volumes from the site in its developed state (**Section 24.6** for calculation methods), and how these should be adjusted to take account of potential future development and climate change (**Section 24.7**).

The runoff rates calculated for the proposed development will exceed the allowable discharge rates. Therefore, the SuDS design will need to include attenuation storage that will fill during rainfall events and/or infiltration components that mean that runoff does not occur. Calculation methods for attenuation storage are set out in **Section 24.9**.

The volume of runoff from the proposed development will also exceed the allowable discharge volumes. Therefore, the SuDS design will need to "use" the runoff (**Chapter 11**), infiltrate the runoff (**Chapter 25**) and/or store and tightly control an additional storage volume, referred to as Long-Term Storage (**Section 24.10**).

Where runoff volumes before development are low, this reflects the presence of more permeable soils. Therefore, although the estimated runoff volumes for the proposed development will be significantly greater, it should be possible to infiltrate a large proportion of this volume, provided that the groundwater is adequately protected (**Section 26.3**).

Designing the site to deliver adequate Interception (the prevention of runoff from the site for the majority of small rainfall events), as required by water quantity standard 1, is set out in **Section 24.8**.

- **Section 24.11** describes how to design drainage components that convey flow from one point on the site to another, up to a specified standard of service
- **Section 24.12** describes design methods for managing flows greater than this standard (ie designing for exceedance flow management).

24.2 RUNOFF ESTIMATION METHODS

24.2.1 An overview of available methods

There are several methods that can be used for estimating peak runoff rates and runoff volumes. Catchment runoff models, adjusted for the size of the site, tend to be used for predicting runoff from greenfield sites. When predicting the response of a developed site, models that represent the existing or proposed drainage system are required, taking account of conveyance and storage capacities of drainage components, flow controls and areas likely to flood and store water during extreme events.

The available methods are summarised in **Table 24.1** and described in the sections in this chapter as indicated. Drainage approving bodies may specify the methods that they require to be used for drainage submissions, or they may leave method selection to the designer. The required approach should always be checked at an early stage in the design process.

Some of these methods are old and there are more recent methods likely to produce better runoff estimates. However, these older methods tend to be simpler and are not dependent on software that has to be purchased. Where the expertise and software required to design and approve systems using the more recent methods is available, the newer methods should be used. Different methods are likely to give different runoff estimates, which could influence the storage volumes required for the drainage system and thus the scheme cost and viability.

24.2.2 Runoff areas to be used in calculations

The runoff area used in any of the runoff estimation methods should be consistent; for example, if the whole site area is used in the greenfield runoff rate calculations, the whole site should also be represented in the runoff calculations for the proposed development. If there is a landscaped area in the developed scenario that discharges directly to receiving waters and does not contribute to the drainage system (so is excluded from the calculations) then this area should also be excluded from the greenfield calculations.

24.2.3 Rainfall to be used in calculations

In order for assessments to be made of the likely rate and volume of runoff from a developed site or catchment, a depth of rainfall and/or rainfall profile is required. This is also required for assessment of greenfield rates if a rainfall–runoff modelling approach is adopted. To date, design rainfall event methods have normally been used that are based on the use of fixed rainfall depths for different return period events and standard rainfall profiles (eg the FEH depth-duration-frequency rainfall model – CEH, 1999). The alternative approach, which is becoming more common for some applications, is to use a continuous time series of rainfall to generate a time series of flows from which frequency curves can be generated. These rainfall time series can come from observed rainfall data, if the series is long enough and appropriately quality assured and calibrated, or can be statistically generated from a number of observed datasets. The two approaches are described in the following sections.

TABLE 24.1 Summary of runoff estimation methods

Runoff estimation method	Reference	Greenfield site		Developed site		Section ref
		Peak runoff rate	Runoff volume	Peak runoff rate	Runoff volume	
FEH ReFH2	Kjeldsen (2007)	✓[1]	✓[1]	✓[3]	✓[3]	24.3.1
FEH statistical method	Kjeldsen *et al* (2008)	✓[1]				24.3.1
IH124	Marshall and Bayliss (1994)	✓[1,2]				24.3.2
FSSR16	NERC (1985)		✓[1,2]			24.4
Modified rational method	HR Wallingford (1981)			✓[3]		24.6.2
Wallingford – Fixed	HR Wallingford (1981)			[4]	[4]	24.6.3
Wallingford – Variable	Packman (1990), Osborne (2009)			✓	✓	24.6.3
UKWIR	UKWIR (2014)			✓	✓	24.6.3

Notes

1 The Environment Agency (through the joint EA/Defra/NRW/Welsh Government FCERM research and development programme) is currently undertaking research that will improve small catchment and plot-scale flood and hydrograph estimation. The intention is for the research and new methods to be available to practitioners in 2017. Some interim outputs are already available (Faulkner *et al*, 2012).

The research is investigating three approaches:

- a full hydrological analysis method for watercourses (using FEH software and catchment descriptors)
- a rapid assessment method for watercourses (using FEH catchment descriptors)
- a specific plot-scale method with a free-to-access tool and input characteristic data

SuDS practitioners undertaking hydrological analysis from 2017 onwards should check for the latest guidance and recommendations on the Environment Agency R&D web pages or the FEH development pages (hosted on the CEH website).

2 FEH methods are preferred.

3 Simple method, relevant for initial design estimates and very simple sites.

4 No longer recommended, but included here as it is still used in current modelling software packages.

Design rainfall

The standard approach currently used by drainage engineers is to use design rainfall events with specific return periods and durations. These were developed originally in the *Flood Studies Report* (FSR) (NERC, 1975) and have been developed further in the *Flood Estimation Handbook* (FEH) (CEH, 1999), and subsequent revisions (Stewart *et al*, 2013). They are routinely used as inputs to greenfield runoff and development drainage models from which flow hydrographs and drainage system performance assessments are then produced.

The FSR/FEH methods provide two profiles: a summer (peakier, with higher intensities) profile and a winter (flatter, with lower intensities) profile. EA/Defra research into rainfall frequency found that seasonal adjustments were applicable to all durations (Stewart *et al*, 2013). Osborne (2012) suggests that, for shorter duration events, winter events should have a smaller total depth.

Summer profiles usually give the worst-case scenarios for sizing piped systems or components receiving direct runoff from impermeable surfaces. Winter profiles generally give the worst case when sizing storage and downstream attenuation components. This is because of the increased runoff generated for winter events due to higher catchment wetness parameter values, which result in larger storage requirements. Although the FEH can be used for durations as short as 30 minutes, flood estimation guidance from the EA (2015) currently recommends that, for shorter durations, FSR rainfall statistics should be used to scale down the corresponding FEH 1-hour rainfall.

The critical duration is the length of rainfall event that results in the greatest flow rate, flood volume or flood level (depending on the purpose of the analysis) at a particular location. It is common for the critical duration to be different at different points in the drainage system, with different SuDS components having different critical durations. This results in a site designer having to use a matrix of events of different return periods and durations to ensure that the design criteria for the system are met at all points. Return periods from 1:1 year to 1:100 years (or 1:200 years in Scotland) and durations from 15 minutes to 48 hours are often required to be assessed.

For greenfield sites, the event duration is not always required, as the estimation of the peak rate of runoff can be based on correlation equations that do not use event rainfall data as an input. However, there are some greenfield runoff models that generate a flow hydrograph from rainfall and, for these, the design event duration is estimated by the models.

Time series rainfall

Continuous rainfall data is a time series of observed (where available) or statistically generated rainfall depths (where observed records are unavailable or too short for the required application). Time series rainfall is not yet routinely used in the design of surface water management systems, due to its inconsistent availability, cost and processing demands. However, in the case of SuDS, time series rainfall allows more accurate estimates of runoff, taking account of infiltration, soil moisture storage and release and evapotranspiration processes. It also allows estimates of subannual event frequencies and associated durations and velocities, which is useful for the assessment of treatment effectiveness.

The length of the rainfall series should be long enough to ensure that the complexity of rainfall characteristics and related aspects, such as dry periods, are properly taken into account. A minimum series length of at least twice, and preferably three times, the design return period of the system is recommended.

24.3 GREENFIELD SITES: PEAK RUNOFF RATE ESTIMATION

Estimated peak runoff rates for the development site in its greenfield condition for a range of return periods are normally used to define the discharge limits for a new development site.

For greenfield sites, the peak runoff rate for any particular return period is related to the site's catchment characteristics (including soils). The values derived from any analysis should be regarded as approximate, because prediction of runoff from very small catchments will always be imprecise. Furthermore, all runoff estimation methods have been developed using river flow information from much larger catchments than the average development site. However, it has been demonstrated in recent research that there is little evidence that the FEH methods perform less well at smaller scales (Faulkner *et al*, 2012). It should be understood that the overall objective of using an agreed method is to provide a consistent and reasonable estimate upon which storage design can be based, rather than finding the exact runoff rate for any specific site (which is not possible).

The current approaches recommended for calculating greenfield runoff rates are described in the following sections. However, the method used at a particular site should always be agreed with the drainage approval body. Further guidance is provided in EA (2015) and Faulkner *et al* (2012).

FEH methods should be the preferred approach for developing runoff estimates for use in surface water management design, but their use currently depends on access to the FEH documentation and software and suitable hydrological modelling expertise. Where FEH tools are not available, and with agreement of the approving body, the Marshall and Bayliss (1994) approach can be used as an alternative method. From 2017, new recommendations for estimating greenfield runoff rates and volumes will be published (see Note (1) for **Table 24.1**).

It should be noted that Marshall and Bayliss (1994) is more likely to underestimate runoff rates than FEH methods, potentially leading to overdesign of attenuation storage components (Faulkner *et al*, 2012).

24.3.1 Flood Estimation Handbook (FEH)

The FEH methods of flood estimation (CEH, 1999), together with subsequent revisions, superseded the FSR (NERC, 1975) as standard practice for catchment rainfall and runoff analysis in the UK in 1999. Two main approaches for flood frequency estimation are provided:

- statistical method
- rainfall-runoff method (ReFH2)

These are described in the following sections.

FEH statistical method

The FEH statistical method allows estimation of the complete flood frequency curve in any gauged or ungauged catchment in the UK. Details of the updated method can be found in Kjeldsen *et al* (2008), and only a brief summary is presented here.

EQ. 24.1 Estimating the flow frequency curve using the FEH statistical method

The peak rate of runoff for any return period is determined by multiplying an "index flood" by a return period "factor". For example, for the 1:100 year peak runoff rate, this is:

$$Q_{100} = Q_{med} \times GC_{100}$$

where:

Q_{100} = 100 year peak runoff rate
Q_{med} = index flood
GC_{100} = 100 year growth curve factor

The index flood can either be computed from relevant observed flows, or can be estimated using an equation where it is related to a number of hydrological parameters termed "catchment descriptors", which are digitally mapped for the UK (and provided as part of the FEH software). On the FEH CD-ROM 3 catchment descriptor map, average values are provided for the catchment area associated with each defined point along a watercourse. It is not, therefore, possible to determine the relevant descriptors for a specific development site using the current software. The CD-ROM is to be replaced by a web-based delivery service in autumn 2015, and it is planned that future updates will provide some catchment descriptors relevant to individual points or small areas.

For catchments or sites smaller than 50 ha (0.5 km^2), it is suggested that runoff estimates should be made using the methods applied to the nearest suitable catchment above this threshold for which descriptors can be extracted, and then the rates are scaled down by the ratio of catchment area to plot size (Faulkner *et al*, 2012). The decision to translate FEH estimates from catchment scale to plot scale should be accompanied by an assessment of whether the study site is sufficiently representative of the surrounding catchment area. In particular, checks should always be made of the HOST soil class suggested by FEH, by inspection on site. Alternatively, if the FEH software is not used, then an agreed site-specific set of parameters can be used.

The flood frequency (flows for different return period events) estimation procedure therefore consists of three stages:

1. **Estimate the index flood** (defined as the median annual maximum flood, Q_{med}), either from observed annual peak flow data or from catchment descriptors. The catchment descriptor equation is given in **Equation 24.2**. The Q_{med} estimate can be improved where flows are available from nearby, similar gauged catchments using methods published by Kjeldsen (2014).
2. **Derive an appropriate growth curve.** At a gauged site, flood frequency analysis techniques are applied to either gauged annual maximum and/or peaks-over-threshold flood peak data where available. At an ungauged site, the FEH pooling-group software package, WINFAP, is used to create

a pooling-group of “hydrologically similar” gauged catchments (ie catchments showing similarity with regard to key catchment descriptors: catchment area (AREA), standard annual average rainfall (SAAR), flood attenuation from reservoirs and lakes (FARL) and floodplain extent (FPEXT)). Flood growth curves are then created through analysis of the pooling-group flood peak data.

3 **Evaluate the full flood frequency curve.** The flood frequency curve is estimated as the product of the index flood and the growth curve. Peak flow rates for each return period are read from this flood frequency curve.

EQ. 24.2 **FEH statistical method: catchment descriptor equation**

$$Q_{med.cds} = 8.3062\, AREA^{0.8510} \times 0.1536^{(1000/SAAR)} \times FARL^{3.4451} \times 0.0460^{BFIHOST^2}$$

where:

$Q_{med.cds}$	=	median annual maximum flood estimated from catchment descriptors
AREA	=	the area of the catchment in km²
SAAR	=	Standard Average Annual Rainfall for the period 1961–1990 in mm
FARL	=	a measurement of the attenuation influence of water bodies (eg lakes) in the catchment; it is unlikely that *FARL* will be relevant for development site runoff estimation, so this factor becomes 1.0 and therefore drops out
BFIHOST	=	a measure of the level of baseflow (ie ongoing runoff) from the catchment; the measure is provided within the FEH software or, if a suitable site soil assessment is available, then IH126 **Table 2.12** (Boorman *et al*, 1995) can be used to allocate a HOST category to the site soils, and IH126 **Table 3.4** can then be used to obtain a corresponding value for *BFIHOST*.

Revitalised FSR/FEH rainfall-runoff method (ReFH2)

The revitalised FSR/FEH rainfall-runoff method (ReFH) was developed as an event-based approach to design flood estimation and replaced the previous FSR method. Details of the method can be found in Kjeldsen (2007) and subsequent updates (CEH and WHS, 2015). The current version of the method, ReFH2, also includes a component for incorporating the influence of the runoff from paved surfaces on runoff rates and volumes described by Kjeldsen *et al* (2013) (**Section 24.5**). Only a brief summary is presented here. The method uses an event-based rainfall-runoff model, to convert design storm events of appropriate duration and return period into a corresponding design flood event of similar return period. As this method produces runoff hydrographs, it will provide an estimate of greenfield runoff volumes as well estimates of the peak flow rate.

The ReFH model has four model parameters controlling the following:

- hydrological losses (maximum soil capacity, C_{max})
- routing using a unit hydrograph (time to peak, T_p)
- baseflow recharge (BR)
- baseflow lag-time (BL)

and two initial conditions:

- initial depth of water held in the soil (C_{ini})
- initial baseflow at the start of an event (BF_0)

The four parameters and two initial conditions are estimated using catchment descriptors available from the FEH CD-ROM 3 software. The design storms are generated using the FEH rainfall depth-duration-frequency (DDF) model (Faulkner, 1999), also included within the ReFH2 software package.

For catchments smaller than 50 ha (0.5 km²) and small plots of land, it is currently recommended that the model is applied to the nearest suitable catchment above this threshold for which descriptors can be derived, and then the hydrographs are scaled down by the ratio of catchment area to plot size (Faulkner *et al*, 2012). Alternatively, the new ReFH2 software package also includes parameter equations for plot-scale application.

As with the statistical method, the decision to translate FEH estimates from catchment scale to plot scale should be accompanied by an assessment of whether the study site is sufficiently representative of the surrounding catchment area. In particular, checks should always be made of the soil class suggested by FEH, by inspection on site.

The original ReFH1 method is not recommended for use to predict the response of greenfield catchments defined as permeable (*BFIHOST* > 0.65), because it is likely to underpredict the catchment response. Through revised initial conditions, the ReFH2 method has addressed this limitation (CEH and WHS, 2015)

24.3.2 Flood estimation for small catchments (IH124)

The Marshall and Bayliss (1994) approach was the result of a study aimed at improving the characterisation of flood response on small catchments (for areas less than 25 km²), especially on relatively permeable, dry, partly urbanised catchments. They presented new equations for time to peak based on FSR catchment characteristics for both part-urban and rural catchments. The study also introduced a revised version of the FSR regression equation for the mean annual flood (Q_{BAR}), based on gauged records for 71 small rural catchments. However, unlike the catchments used in the same study for the investigation of flood response, many of these smaller 71 catchments were upland, relatively wet and impermeable. Only nine had SAAR values of under 800 mm, while 30 catchments were in high *SAAR* areas (over 1500 mm).

The flood frequency (flows for different return period events) estimation procedure consists of three stages, as for the FEH approach:

1 Estimate the Q_{BAR} (mean annual flood)

The IH124 equation for Q_{BAR} is given in **Equation 24.3**.

EQ. 24.3 IH124: Catchment descriptor equation

$$Q_{BAR(rural)} = 0.00108\ AREA^{0.89} \times SAAR^{1.17} \times SOIL^{2.17}$$

where:

$Q_{BAR(rural)}$	=	mean annual flood (a return period in the region of 2.3 years)
AREA	=	area of the catchment in km²
SAAR	=	Standard Average Annual Rainfall for the period 1941–1970 in mm
SOIL	=	soil index, which is a value found from the FSR soil maps or the WRAP map of the Wallingford procedure, and represents an estimate of the proportion of runoff from the catchment surface*

Where the site is less than 50 ha, the formula should be applied for 50 ha and the result factored based on the ratio of the actual site area and the applied area (50 ha).

* If a reliable surface soils class map of the site is available, then IH126 **Table 2.12** (Boorman *et al*, 1995), can be used to allocate a HOST category to the site soils. IH126 **Table 4.16** can then be used to obtain a corresponding value for SPR (note this is stated as a percentage, rather than a proportion so will need to be divided by 100). The extra detail provided by HOST is generally likely to provide an improved estimate of SPR than using the coarse categorisation of the five SOIL categories, although it should be recognised that SPRHOST was not originally derived for use in the IH124 equation, and Appendix 5 of Kellagher (2013) should be referenced for further guidance on this issue.

2 Select an appropriate growth curve

Q_{BAR} can be factored by the UK FSR regional growth curves (NERC, 1977) for return periods < 2 years and NERC (1993) for all other return periods to obtain peak flow estimates for required return periods.

These regional growth curves are constant throughout a region, whatever the catchment type and size. In reality it is likely that growth curves become steeper for smaller catchments, so the regional curves may tend to underestimate high return period flows potentially leading to overdesign of attenuation storage components.

The hydrological regions and corresponding growth curves are given as **Figures 24.1 and 24.2, and Table 24.2**.

3 Evaluate the full flood frequency curve.

Peak flow rates for each return period can then be estimated as the product of Q_{BAR} and the relevant growth curve factor.

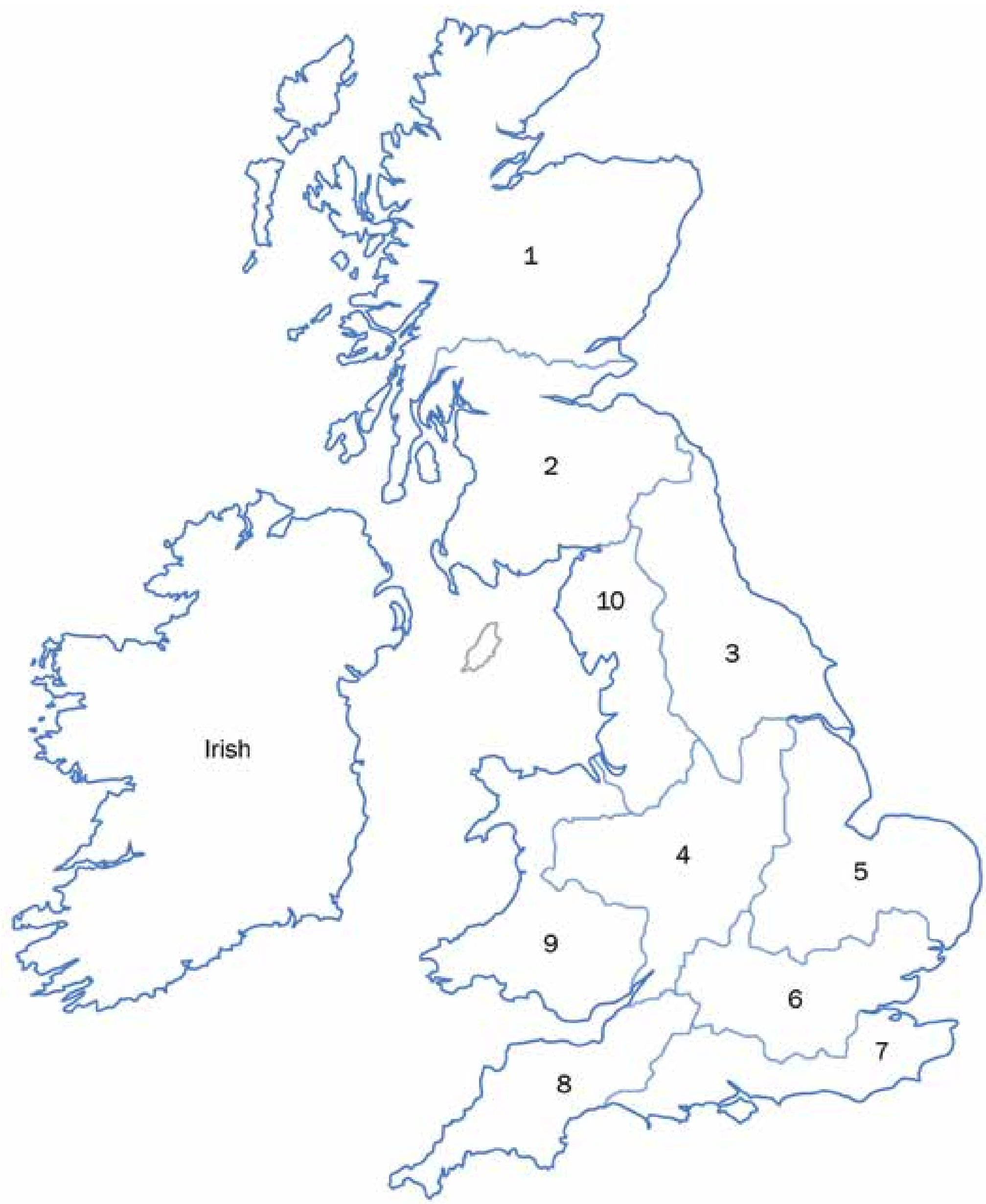

Figure 24.1 Hydrological areas

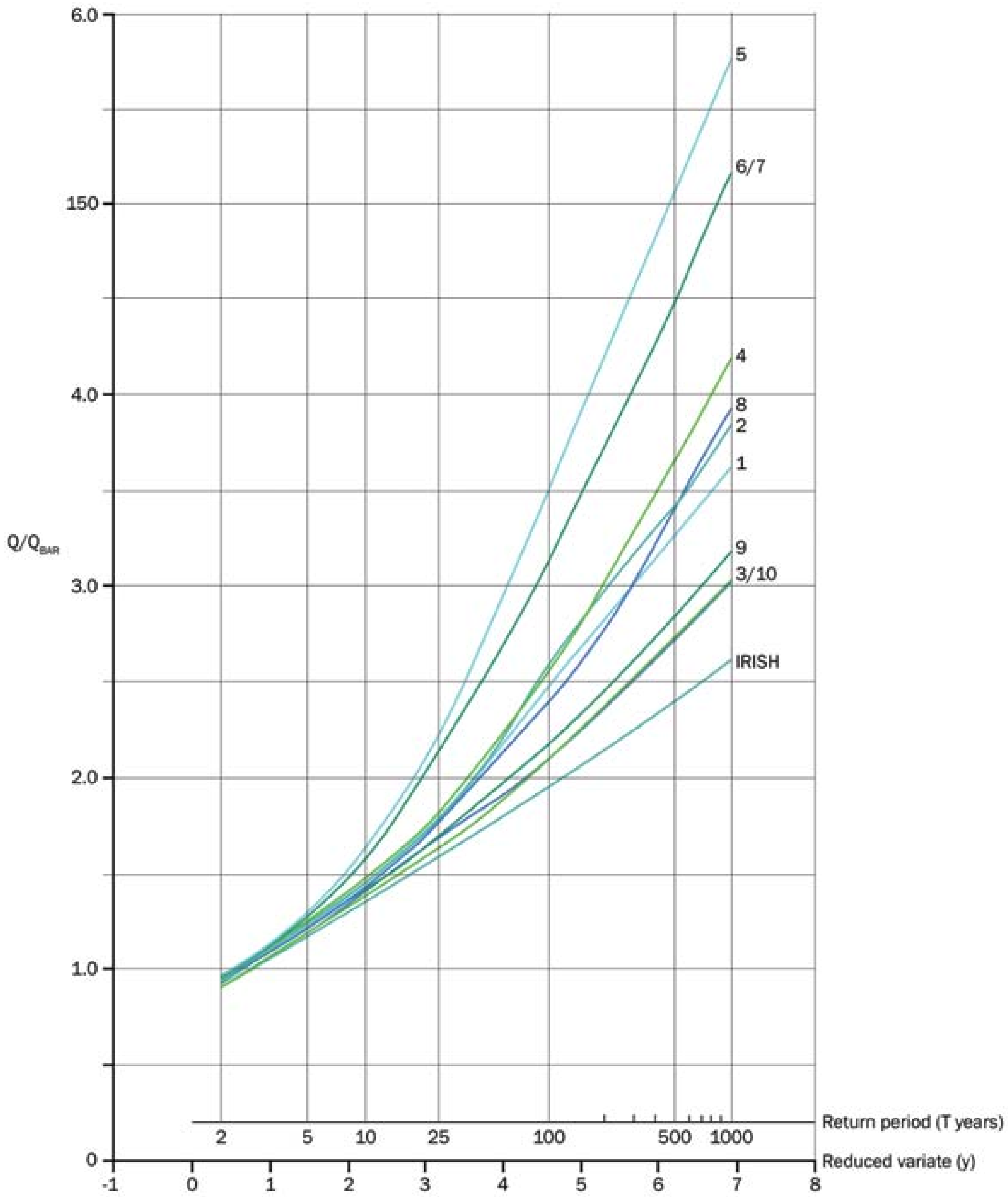

Figure 24.2 UK and Ireland growth curves (after NERC, 1975)

TABLE 24.2 UK and Ireland growth curve factors (after NERC, 1993)

Hydrometric area	Return period								
	1[1]	2	5	10	25	30[2]	50	100	500
1	0.85	0.90	1.20	1.45	1.81	1.99	2.12	2.48	3.25
2	0.87	0.91	1.11	1.42	1.81	1.99	2.17	2.63	3.45
3	0.86	0.94	1.25	1.45	1.70	1.75	1.90	2.08	2.73
9	0.88	0.93	1.21	1.42	1.71	1.80	1.94	2.18	2.86
10	0.87	0.93	1.19	1.38	1.64	1.70	1.85	2.08	2.73
4	0.83	0.89	1.23	1.49	1.87	1.99	2.20	2.57	3.62
5	0.87	0.89	1.29	1.65	2.25	2.55	2.83	3.56	5.02
6/7	0.85	0.88	1.28	1.62	2.14	2.40	2.62	3.19	4.49
8	0.78	0.88	1.23	1.49	1.84	1.98	2.12	2.42	3.41
Ireland	0.83[2]	0.95	1.20	1.37	1.60	1.65	1.77	1.96	2.40

Notes

1 1 year return period growth curve factors are taken from NERC (1977)

2 30 year (and 1 year for Ireland) return period growth curve factors are interpolated estimates

24.4 GREENFIELD SITES: RUNOFF VOLUME ESTIMATION

The greenfield runoff volume for a site is used to define the allowable runoff volume that can be discharged (at greenfield flow rates) from a development site, in order to protect downstream areas from increased flood risk due to the development. This is usually defined as the 1:100 year 6 hour duration design event, based on research by Kellagher (2002).

The use of a single event provides a simple, generic approach. The 6 hour duration event is based on the need to provide adequate protection for small to medium-sized watercourses that tend to be most at risk from the effects of urbanisation. At alternative criterion may be specified locally.

The objective of this criterion is to allow original greenfield runoff rates to continue, while also controlling the runoff volume. The alternative is to accept higher volumes of discharge, but to limit all the runoff to much lower flow rates (eg < 2 l/s/ha or as agreed with the local drainage approving body and/or environmental regulator), otherwise downstream flood risk is likely to rise.

An evaluation of the greenfield runoff volume for the 1:100 year 6 hour event can be avoided by using a simple method to estimate the difference in runoff volume between the developed and greenfield conditions (**Section 24.10**).

Greenfield runoff volumes can be calculated in one of two ways:

1. Using equations that predict the proportion of runoff (percentage runoff: PR) that occurs from the site for the design event.

   A simple assumption can be made that the proportion of rainfall that runs off a greenfield site is not dependent on catchment wetness, and is thus equal to the SPR (standard percentage runoff) value for the site soil type. The assumption that SPR is the runoff proportion is a reasonable approximation for extreme events, even though the actual runoff is also related to catchment wetness.

   SPR or PR values are then used to determine the runoff volume by multiplying them by catchment area and rainfall depth:

   Runoff volume = (SPR or PR) × catchment area × rainfall depth

The PR model from NERC (1985) is presented in **Equation 24.4**.

2 From design event runoff hydrographs (where rainfall-runoff methods are being used (**Section 24.3.1**). This should be for the 100 year, 6 hour event. The difference in approach between 1 and 2 is that, in the rainfall-runoff model, the standard and dynamic components of percentage runoff are computed explicitly based on the design estimate of initial soil water content and the dynamic evolution of soil water content during the course of the rainfall event.

An important issue to note is the crucial influence of soil type on runoff volume. In practice, this indicates that developments on sandy soils create significant extra runoff volume compared to the pre-development condition (but it should be possible to manage this volume using infiltration), while developments on clays generate relatively small amounts of extra runoff (where infiltration design is less likely to be appropriate).

EQ. 24.4 **Fixed percentage runoff model (from NERC, 1985)**

The fixed percentage runoff method correlates runoff volume (as percentage runoff) with soil type, storm depth and other easily derived parameters:

$$PR_{RURAL} = SPR + DPR_{CWI} + DPR_{RAIN}$$

where:

PR_{RURAL} = total percentage runoff for the greenfield catchment for a particular event

SPR = standard percentage runoff, which is the fixed component of the percentage runoff and can be computed as either a function of the five soil class fractions defined by the FSR WRAP map:

$$SPR = 10S_1 + 30S_2 + 37S_3 + 47S_4 + 54S_5$$

or from the *SPR* values for each of the FEH HOST soil class fractions:

$$SPR = SPR_1HOST_1 + SPR_2HOST_2 + \cdots + SPR_{29}HOST_{29}$$

DPR_{CWI} = the dynamic component of the percentage runoff. This parameter reflects the increase in percentage runoff with increasing catchment wetness. The catchment wetness index (*CWI*) is a function of the average annual rainfall (**Figure 24.3**).

$$DPR_{CWI} = 0.25\,(CWI - 125)$$

The DPR_{RAIN} is the second dynamic component that increases the percentage runoff from large rainfall events.

$$DPR_{RAIN} = 0.45\,(P - 40)^{0.7} \text{ for } P > 40 \text{ mm (where } P \text{ is event rainfall depth)}$$

$$DPR_{RAIN} = 0 \text{ for } P \leq 40 \text{ mm}$$

continued...

continued from...

EQ. 24.4 **Fixed percentage runoff model (from NERC, 1985)**

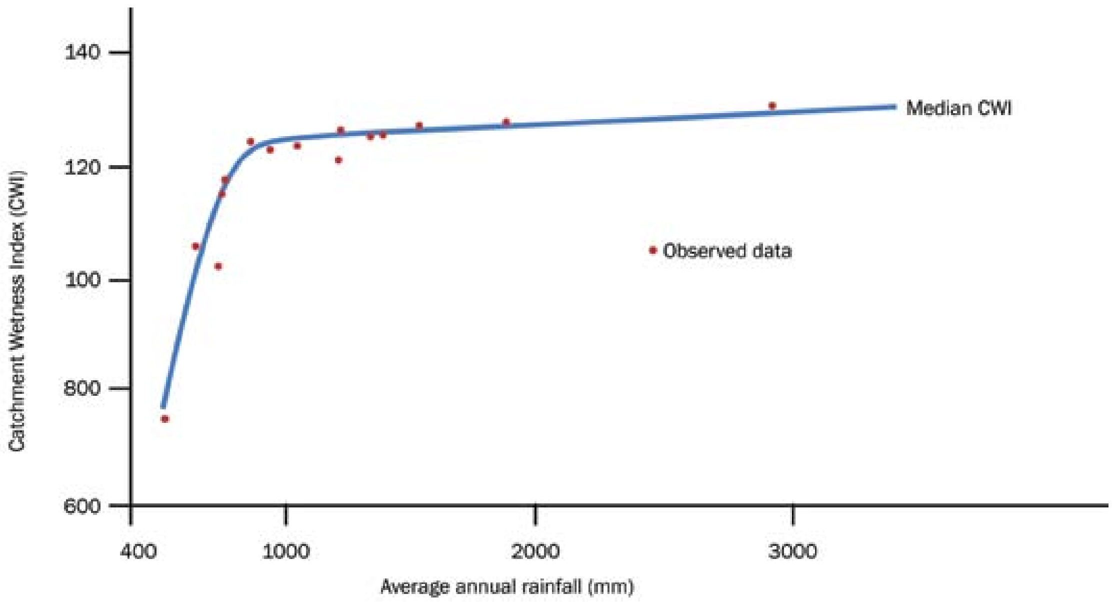

Figure 24.3 Catchment wetness index (CWI) vs Standard Average Annual Rainfall (SAAR) (from NERC, 1975)

24.5 PREVIOUSLY DEVELOPED SITES: PEAK RUNOFF RATE AND RUNOFF VOLUME ESTIMATION

Where a site has been previously developed, there may be agreement that discharge limits can correspond to rates that exist for the current state of the site (or a proportion of those rates). The preferred position should be to aspire to meet greenfield runoff rates and volumes, and any relaxation of this should be subject to an assessment of the current and future capacity of the receiving sewer or watercourse and agreement with the environmental regulator, drainage approving body and/or relevant sewerage company. In many cases, runoff volume may be as important as flow rate in terms of protecting receiving water body flood risk. Local policies, specifically strategic Flood Risk Assessments should be checked with respect to runoff control requirements for previously developed sites.

Runoff characteristics for a previously developed site can be estimated in a number of ways:

1. Any land that has been previously developed is likely to have had a system in place to drain surface water runoff from the site. This drainage system may or may not have included storage and flow control systems. Where any drainage system is still operational, peak flow rates at the outfall for the relevant return periods (usually 1:1 year, 1:30 year and 1:100 year) can be demonstrated by producing a simulation model that includes an accurate representation of the drainage system and site area contributions – thus allowing derivation of an appropriate head–discharge relationship at the outfall.

   It is recognised that existing drainage systems will probably be overwhelmed for the 1:30 and 1:100 year events and therefore the actual rate of discharge from the site in such scenarios is likely to be increased by overland flow contributions or surcharging. However, these effects should not be accounted for, and the discharge limit should be based solely on the flow rate from the piped system (thus providing a conservative estimate).

2. Where records of the previously developed system are not available (so that the hydraulic characteristics of the system cannot be determined) or where the drainage system is not in reasonable working order (ie broken, blocked or no longer operational for other reasons), then one of the following approaches can be adopted:

   a. The first approach assumes that the runoff from the site is represented by greenfield response from impermeable soils. The methods for greenfield peak runoff estimation (**Section 24.3**) and volume estimation (**Section 24.4**) should therefore be applied using a high runoff soil type that better represents the high levels of runoff that take place from developed surfaces (eg FSR Soil Type 5 or equivalent lowest permeability soil type for the runoff estimation method used in the design). This approach should only be used if the site is predominantly urbanised, and it would not be appropriate for sites with, for example, permeable soils and limited development. In these situations greenfield runoff rates would normally be a more appropriate target.

b Runoff from the site can be estimated using the urbanisation methods within the ReFH2 software. Using this method, the impervious area can be set to the area of the impervious surfaces in the development site.

24.6 THE PROPOSED DEVELOPMENT SITE: PEAK RUNOFF RATE AND RUNOFF VOLUME ESTIMATION

24.6.1 Introduction

The runoff from the proposed development surfaces will be required as inflows to the drainage system.

Site developments are characterised as having two main categories of surfaces: impermeable (paved and roof) areas and permeable (grassed and vegetated) areas. These surfaces have different runoff characteristics, so both need to be represented in calculations and models.

Surface water management systems should usually be designed to accommodate the predicted effects of future climate change by factoring the design rainfall intensities by a climate change uplift factor. This is discussed in **Section 24.7.1**. They should also consider likely future development and urban creep on the site, and suggested factors are presented in **Section 24.7.2**.

An *initial* assessment of the peak rates of runoff from developed surfaces can be made using either the simple “modified rational” method, described here or the ReFH2 urbanisation method, as described in **Section 24.5** for the previously developed site. These methods are useful for assessing peak flow rates for initial sizing of inlets and conveyance systems. However, a volumetric method using a simulation model is normally required for sizing of storage components, owing to the need to determine multiple critical durations for individual points in the drainage system. The modified rational method provides a direct estimate of runoff rate from rainfall intensity, whereas a runoff model is used within a hydraulic simulation model that also describes the routing and attenuation of the collection and conveyance system in order to output a peak flow rate.

Whether a peak flow estimation or a volumetric approach is used, there is a need to make assumptions regarding the proportion of runoff that takes place from both impervious and pervious surfaces for a specified rainfall event. This can be estimated based on fixed values, for example as suggested by WRc (2012), or based on a runoff model.

24.6.2 The modified rational method

The peak runoff rate can be estimated using the equation given in **Equation 24.5**.

Volumetric and routing coefficients (C_V and C_R)

The coefficient of runoff was split into two terms when the modified rational method (HR Wallingford, 1981) was originally produced: the volumetric runoff coefficient, C_V (of the order of 0.6) and the routing coefficient, C_R, (of the order of 1.3). However, the routing coefficient (which addresses the fact that some parts of the site will generate flows to a downstream point faster than others) tends to be ignored.

For paved area runoff, the two coefficients are usually incorporated into a single term with a value of between 0.8 and 1.0 – depending on how effectively the catchment is drained and the level of impermeability.

An equivalent approach is required for the pervious area runoff, with the chosen coefficient reflecting the proportion of contributing and non-contributing pervious areas, the soil type, site gradient, event size, likely antecedent conditions etc.

Guidance on runoff proportions from extreme events for different surfaces is provided in NERC (1985).

WRc (2012) is the industry standard produced by water companies for adoption of drainage for new development. It proposes the use of 100% runoff from impermeable areas and 0% runoff from pervious areas. This is known to be suitably conservative for events of between 1:1 year and 1:5 year. However, it is likely to be less appropriate for larger events when the pervious areas start generating significant runoff. For standard developments that tend to have impermeability ratios of around 50–65%, this assumption is regarded as being acceptable, at least in terms of initial design and analysis, as it avoids having to use the more complicated runoff models.

EQ. 24.5 Modified rational method equation to determine peak flow rates

$$Q = 2.78\,C\,i\,A$$

where:

Q = design event peak rate of runoff (l/s)

C = non-dimensional runoff coefficient which is dependent on the catchment characteristics

$$C = C_V\,C_R$$

where C_V = volumetric runoff coefficient

C_R = dimensionless routing coefficient

i = rainfall intensity for the design return period (in mm/hr) and for a duration equal to the "time of concentration" of the network

A = total catchment area being drained (ha)

Note: 2.78 is a conversion factor to address the rainfall unit being in mm/hr.

Rainfall intensity (i)

For the rational method to be used for design purposes, the rainfall intensity (i) for the design time of concentration needs to be known. This gives the maximum flow rate at a point in the network in order to size the conveyance component. The rational method assumes that the whole catchment contributes runoff to a point in the system that has the longest time of concentration of any drainage branch. The rainfall intensity for this duration is used to calculate the flow. Rainfall intensity–duration–frequency curves can be generated using the FSR, the FEH or from appropriate gauged autographic rainfall data.

Alternatively, for an initial assessment of the design of a pipe network (for pipe full flow), a constant rainfall intensity of 35 mm/hr can be assumed, or 50 mm/hr may be required by some approving bodies for a more conservative solution (May and Kellagher, 2004).

For design of piped urban drainage networks a time of entry of 3–5 minutes is assumed, and then the time taken to travel through the network from the furthest point in the catchment at the pipe-full velocity is added. Advice on this is provided in the modified rational method in Volume 4 of the Wallingford Procedure (HR Wallingford, 1981).

24.6.3 UK runoff models

UK runoff models

There are two methods currently recommended for use in the UK for predicting percentage runoff from developed areas for detailed design purposes:

- variable UK runoff model
- UKWIR UK runoff model

The "old UK" equation or "fixed UK" runoff model (HR Wallingford, 1981) was the original runoff model of the Wallingford Procedure, but this was officially replaced by the "variable UK" runoff model equation (Packman, 1990), although there are still models around that use the fixed runoff model. Revisions to the old equation are presented together with the variable UK runoff model equation in the Wallingford Procedure for Europe, (Kellagher, 2000), along with guidance on their use. The UKWIR runoff model (UKWIR, 2014) has only recently been developed, and industry is currently assessing its effectiveness. This latest model is intended to address some of the limitation of the variable UK runoff model and to take account of the more detailed HOST classes of soil that are available digitally across the UK. The research report provides a comparison of the three equations and data on their development, advantages and limitations.

The term "Wallingford Procedure" is usually used to describe the process or runoff modelling, simulation modelling (using hydraulic routing methods) and model verification, but only the runoff modelling (ie estimation of the rate and proportion of runoff from surfaces) is covered here.

All three methods are regression equations where each surface type is assigned a proportion of runoff. In the fixed UK runoff model, the runoff was a fixed coefficient (although the runoff coefficient value took into account antecedent conditions). Both subsequent equations have an runoff coefficient that increases as the ground gets wetter through the storm.

The model equations are summarised in the following sections.

Fixed UK runoff model

The "fixed UK" runoff model (or old UK equation) is a regression equation that was calibrated against a large number of events recorded in the UK and overseas. It is given in **Equation 24.6**.

This method is now outdated and no longer recommended. It has been replaced by later equations and is only included here for completeness, as it is still used in some industry models.

EQ. 24.6 **Fixed UK runoff model**

$$PR = 0.829\,PIMP + 25\,SOIL + 0.078\,UCWI - 20.7$$

where:

PR = percentage runoff for the contributing catchment

PIMP = percentage impermeability (0–100) obtained by dividing the total directly connected impervious area (both roofs and roads) by the total contributing area

SOIL = an index of the water-holding capacity of the soil (0.15–0.50), based on the FSR WRAP parameter, obtained from FSR (NERC, 1975) or Wallingford Procedure mapping (HR Wallingford, 1981)

UCWI = urban catchment wetness index (design values are provided by referring to a figure relating *UCWI* to the annual average rainfall for that location (**Figure 24.3**).

Variable UK runoff model

The "variable UK" runoff model (or "new UK" equation) was introduced by the Institute of Hydrology as a replacement to the original fixed UK runoff model (old UK equation). The dataset used in developing a calibrated model was a subset of the same data used for the development of the previous approach.

This model provides a variable (increasing) percentage runoff during a rainfall event, in order to take account of changes in catchment wetness as the storm progresses. This aspect is particularly important for long duration events where losses reduce as the pervious surfaces become saturated. The model takes the form set out in **Equation 24.7**.

EQ. 24.7 Variable UK runoff model

$$PR = IF \times PIMP + (100 - IF \times PIMP) \times \frac{NAPI}{PF}$$

where:

PR = percentage runoff
IF = effective paved area factor (**Table 24.3**)
PIMP = percentage impermeability (0–100)
PF = soil moisture depth (mm)
NAPI = 30-day antecedent precipitation index (API) (depends upon the soil type)

This equation effectively divides PR into the two contributions from paved and pervious surfaces. The impervious area runoff is obtained by using an "effective contributing area" proportion, IF (ie from surfaces that run directly into the drainage system). The original recommended values of IF are given in **Table 24.3**. However, IF values have tended to be applied at around 0.7 in practice in most models.

TABLE 24.3 Recommended values of IF

Surface condition	Effective impervious area factor, IF
Poor	0.45
Fair	0.60
Good	0.75

The remainder of the paved area (the component (1 − IF) that does not run directly into the drainage system) is assumed to be a pervious surface and added to the pervious area.

The runoff from the pervious surfaces, and also any non-effective impervious surfaces, are represented by the second part of the equation with a runoff value of NAPI / PF. NAPI is a 30-day antecedent precipitation index (with evapotranspiration subtracted from the rainfall) that is given by a decay function equation with a decay coefficient, C, related to soil type as shown in **Table 24.4**.

Design values for NAPI have never been formally established, although the industry has generally accepted the findings of a paper by Margetts (2002). For more information on this topic, see UKWIR (2014). In practice the NAPI design values for SOIL type 1 and 2 are effectively zero. The values for SOIL type 3 and 4 are normally in the range of 10–25 mm and are related to SAAR (annual rainfall depth) for the location. It should be noted that the basis for the decay coefficient for SOIL type 5 has never been established and the decay value is generally regarded as being too high.

TABLE 24.4 Relationship between SOIL types and decay coefficient C

Soil types	C
1	0.1
2	0.5
3	0.7
4	0.9
5	0.99

The moisture depth parameter, PF, should normally be set at 200 mm. There is very limited guidance on modifying this value, and caution is advised if any changes are made.

UKWIR UK runoff model

The UKWIR UK runoff model (or UKWIR equation) is set out in **Equation 24.8**. It was developed in 2013 to address a number of limitations considered to apply to the variable UK runoff model equation. The following are some of the key limitations addressed:

1. Models calibrated using summer conditions generally underpredict runoff for winter conditions.
2. There is no scientifically approved value for the parameter NAPI for use with design storms.
3. There are improved soil characteristic datasets (HOST categories) available digitally for the UK.
4. The variable UK runoff model incorrectly assumes that runoff occurs from pervious areas for all events, however small the event.
5. It is not correct to assume that the non-effective paved surface component contributes runoff as a pervious surface.

EQ. 24.8 The UKWIR UK runoff model

$$PR = \sum_{n=1}^{N}\left[IF_n \times PIMP_n + (1 - IF_n) \times PIMP_n \times \frac{PI_{pv}{}^{\beta}}{PF_{pv}}\right] + \left[(1 - PIMP_{TOTAL}) \times \frac{((NAPI_s + PI_s)^{Cr} \times SPR)}{PF_s}\right]$$

where:

PR	=	percentage runoff
$PIMP$	=	percentage impermeability of the sub-catchment
IF_n	=	effective impermeability factor for a particular paved surface type
β	=	power coefficient for paved surface
PI_{pv}	=	precipitation index for paved surface with rapid decay coefficient
PF_{pv}	=	soil store depth for paved surface
SPR	=	standard percentage runoff (for both WRAP and HOST soil classes)
PI_s	=	precipitation index for pervious surface with decay coefficient
$NAPI_s$	=	antecedent precipitation index for a particular pervious surface type (with 30-day decay coefficient)
Cr	=	power coefficient for pervious surface
PF_s	=	soil store depth for a particular pervious surface type

As well as addressing the above issues, the development of the UKWIR equation has also taken into account the current and likely future development of runoff tools in urban drainage modelling for both 1D and 2D modelling, and the trend towards the use of continuous rainfall time series and away from design storms.

A description of the parameters in **Equation 24.8** is provided in **Table 24.5**. Other variables (that are embedded in these parameters) are described in UKWIR (2014). Any changes made to default values (eg for calibration scenarios) should be undertaken with all potential implications understood.

TABLE 24.5 UKWIR runoff equation: suggested parameter ranges

Parameter	Default value	Suggested range	Comment
PR	–	0–100	
PIMP	–	0–100	
IF	–	0.5–1.0	Values should be selected between 0.6 and 0.8, depending on how well drained the surface is and the level of impermeability
β	0.5	0.5–0.8	Paved power factor To increase runoff proportion quickly during the early part of the event
PI_{pv}	0	0–5	Initial wetness for paved surfaces Zero at start of event for design storms Non-zero value for continuous time series, but would always be close to zero at start of an event, as decay coefficient is small
PF_{pv}	10 mm	10–50 mm	"Storage" depth for paved and roof surfaces Could differentiate value based on surface type Altering this depth should be carried out in conjunction with the value of β used.
SOIL	–	1–5	WRAP/FSR soil types.
HOST	–	1–29	HOST soil classes
SPR	–	0.10–0.60	Soil runoff parameter (standard percentage runoff) Four SOIL and 29 HOST classes Lower limits applied to SPRHOST
PI_s	n/a	n/a	Decayed cumulative event rainfall Same decay function as NAPIs
$NAPI_s$	10 (for design rainfall, NB location specific)	−15 to +40 (depends on decay coefficient)	Antecedent precipitation index This can be negative where evaporation exceeds rainfall
Cr	0.8	0.8–1.0+	Pervious power factor Value linked to value of PFs Intended to provide greater influence of early rainfall compared to later rainfall during the event
PF_s	35	30–100	Soil store depth Choice is linked to value of pervious power factor

BOX 24.1 A summary of the approach to modelling paved surfaces using the UKWIR UK runoff model

- Runoff modelling of the paved components of a catchment has a fixed runoff component and a variable runoff component.
- The variable runoff component is a function of the rainfall depth and rainfall intensity.
- Each paved surface type (road, roof, indirectly drained areas) should be modelled with their own set of parameters:
  - The fixed runoff component for road surfaces should normally be set to have an effective impermeability of 0.5–0.65.
  - The fixed runoff component for roofs should normally be set to have an effective impermeability of 0.8.
  - The variable components should use a decay coefficient of 0.1, and a "soil" depth of 10 mm.
  - The rainfall depth power factor is set at 0.5 and aims to increase the influence of the early part of the storm in increasing the proportion of runoff.
- All parameters can be used to calibrate the model.

Paved runoff (UKWIR runoff model)

The paved component runoff model is very similar to the variable UK runoff model equation. It has a fixed runoff component (IF × PIMP) and a variable runoff component (1 − IF) × PIMP (to represent rainfall that is "lost" on the paved surface). This second term is therefore separated from the pervious component of the model and routed with the paved surface runoff. It will therefore be more responsive to increasing wetness than the pervious runoff.

The increase in the rate of runoff during the event is now assumed to be non-linear to weight the increase in extra runoff to the early part of the storm depth using a power factor of 0.5. The use of a rapid decay coefficient means that the proportion of runoff is now related to the intensity of the rainfall.

As with the pervious component of the variable UK runoff model equation, the wetness of the paved surfaces is a continuously calculated value. It uses a 30-day analysis period, but the decay coefficient is set to 0.1 to ensure the wetness term (NAPI) rapidly reduces to zero after an event. NAPI is allowed to become negative, to prevent runoff from dry pervious catchments from taking place immediately rainfall commences.

The model allows more than one paved surface category and it is expected that three categories of paved surface would commonly be used (roads, roofs, indirectly drained paved areas); each potentially has its own set of parameters.

Pervious runoff (UKWIR runoff model)

The pervious runoff component is addressed in a similar way to the variable UK runoff model equation. This presumes that all the pervious area in a catchment contributes runoff based on an initial wetness measure, with an increasing proportion of runoff linked to rainfall depth. However, there are a number of significant differences built into the UKWIR equation.

Firstly, NAPI is a 30-day calculation, but it is not a function of soil type. The assumption has been made that antecedent wetness can be represented for all soil types by a single decay function. A value of 0.8–0.9 is proposed.

The second major difference is the calculation of NAPI, which now uses evaporation, and this can result in negative NAPI terms (acting rather like a soil moisture model). This has the important advantage of delivering a negative term for dry periods in summer. When the NAPI term is negative, it is assumed that this results in no runoff taking place from pervious surfaces. This approach was produced to provide an increase in differentiation between summer and winter runoff, thus addressing one of the key requirements of revising the variable UK runoff model.

Design values for NAPI were derived, and UKWIR (2014) should be referred to for details. However, an approximation of 10 mm could be used in the absence of detailed information or analysis.

BOX 24.2 A summary of the approach to modelling pervious surfaces using the UKWIR runoff model

- The equation uses hydrological soil parameters and methods that are currently available to, and understood by, the water industry.
- The use of HOST improves the resolution of soils information and this data can be imported digitally.
- All soils are modelled with one decay coefficient (default 0.8), with the proportion of runoff differentiated by the use of the soil specific term, SPR.
- All parameters can be modified to calibrate the model.
- Runoff from pervious surfaces are zero when the value of NAPI is negative (during dry periods and in the early part of a rainfall event).
- The rainfall depth power factor is set at 0.8, and aims to limit the influence of very large storm events in increasing the proportion of runoff.
- Each pervious surface type (specific soil category or estimated urban soil characteristic) should be modelled with its own set of parameters.
  - The minimum NAPI value is a function of the decay coefficient. It is suggested that a limit is set for the minimum negative value to around 15 mm.
  - The decay coefficient should be in the range of 0.7–0.9 for all soils.
  - The “soil” depth default is 35 mm, but this is linked to the rainfall depth power factor.
  - The minimum value of SPR should be 0.1. Although the maximum value for any soil class is 0.6, there may be circumstances (eg steep hillsides) when a slightly higher value might be justified.
  - The rainfall depth power factor default is 0.8.

Changing of the power factor and the “soil” depth should be considered together, so that a depth of 80–100 mm of NAPI + rainfall depth is needed to achieve a runoff of 1.0 × SPR runoff (ignoring the effects of the decay coefficient).

24.7 CLIMATE CHANGE AND URBAN CREEP ALLOWANCES

When estimating runoff rates from development sites for design events, the computed flow should include an uplift to cater for the effects of climate change impacts on future rainfall intensities. To ensure that flood risk in the catchment does not increase with time, uplift factors on greenfield runoff rates should not be applied. Similarly drainage areas should be applied with urban creep factors to take account of a likely future increases in the impermeability of a site.

24.7.1 Climate change factors

Climate change uplift factors for rainfall intensities, peak river flows and sea level are normally specified by national government or the environmental regulator. They are regularly updated and therefore not provided in this document.

Peak river flow and sea level uplifts will be appropriate when considering the potential impact of receiving water body flood levels on the operation of the SuDS. Rainfall intensity factors will need to be applied to design rainfall depths for the developed site runoff assessment.

Current recommended climate change allowances should be based on the findings of UKCP09, with regional allowances and consideration of uncertainty, rather than fixed national allowances. For some regions, the upper end estimate from the UKCP09 impacts research is much higher than the suggested change factor, and in such scenarios it would be prudent to at least examine the sensitivity of SuDS designs, particularly for high-risk developments, to a range of possible climate change impacts.

The hyetograph rainfall intensity values for the design storm events should be increased by the relevant climate uplift factor for the required design life of the system.

Normally, residential sites use the 2085–2115 design horizon, but shorter horizons may be appropriate for commercial and industrial developments.

It should be noted that storage volumes will approximately increase by the square of any rainfall uplift factor. This means that a 10% increase in rainfall (an uplift factor of 1.1) will result in a 20% increase in storage (uplift factor of 1.21), while a 40% increase in rainfall will nearly double the storage required.

Other climate change projections, including reduced summer rainfall, may have implications for vegetation resilience and water quality performance of SuDS components (water quality criterion 2, **Section 4.2.3**)

24.7.2 Urban creep factors

Urban creep is defined as any increase in the impervious area that is drained to an existing drainage system without planning permission being required, and therefore without any consideration of whether the capacity of the receiving sewerage system can accommodate the increased flow. For example, the construction of patios, conservatories, small extensions, paved driveways etc (post initial construction) may all result in an increase in surface runoff and therefore reduce the level of service of the drainage system.

To allow for future urban expansion within the development, an increase in paved surface area of 10% is often suggested if there is no specified value stipulated by the drainage approval body or planning authority.

24.8 DESIGNING FOR INTERCEPTION

Interception can be defined as the capture and retention on site of the first 5 mm (or other specified depth) of the majority of all rainfall events. Designing for Interception has two key benefits:

1 Runoff characteristics from the site will more closely reflect greenfield runoff behaviour (where runoff will not occur for the majority of small rainfall events) and this will help to protect the morphology and ecology of the receiving surface water body.

2 The pollution load to any receiving surface water body that could potentially be associated with the total runoff volume from all such small events will be retained on site – where it will have time to biodegrade and/or be acted on by natural treatment processes.

Interception can be delivered using one or a combination of processes:

- rainwater harvesting
- infiltration
- evapotranspiration using temporary shallow ponding or storage within the soil or upper aggregate layers

Any Interception method that potentially allows the transfer of contaminants to groundwater via the underlying soil pore water or soil matrix should follow the guidance in **Section 26.7**.

Interception cannot be guaranteed for every rainfall event, due to the variability in evapotranspiration and rainfall through the year and the corresponding variability in soil moisture storage levels. Interception is far less likely to be achievable during extended wet periods where soils are saturated, so for any rainfall event, the design should have an associated probability of delivering Interception for any contributing impermeable area. Receiving streams and rivers are likely to be under greater stress during summer months (with lower available dilution levels and with flora and fauna less likely to be tolerant of rapid flow rates and high water levels at this time of year). It is therefore suggested that any criteria for compliance should differentiate between summer and winter; for example, for a 5 mm Interception depth, compliance for 80% of rainfall events could be required during summer months and 50% compliance during winter months.

Designing systems to achieve specific probabilities of compliance requires analysis using a model of the drainage system and continuous time series rainfall data, which may not be an approach that is accessible or usable by designers. Simple approaches are therefore set out in **Box 24.3**. Such approaches cannot evaluate the actual probability of compliance, but can provide a useful design aid. Alternatively, some assumed compliance scenarios are set out in **Table 24.6**.

BOX 24.3 **Simple approaches to Interception delivery and compliance assessment**

Rainwater harvesting only

Rainwater harvesting systems, whether designed for just reducing potable water demand or for surface water management as well, can be assumed to deliver effective Interception for the contributing surfaces.

Infiltration (where the system is designed for this purpose)

Where SuDS are designed to infiltrate more than 5 mm from the contributing catchment for all events, then Interception will be effectively delivered.

Evapotranspiration only

Assuming that rainfall is evenly distributed through the year, the effective monthly runoff contribution from 1 m^2 of paved surface is:

$$30 \text{ days} \times (700 \text{ mm}/365 \text{ days}) \times 50\% \text{ percentage runoff} = 29 \text{ mm of effective runoff}$$

(Note: the 700 mm represents the annual average rainfall, this can be varied depending on location; 50% runoff is appropriate for small rainfall events.)

The evaporative capacity of 1 m^2 of vegetative surface (without any infiltration capacity) for a peak summer month approximates to:

$$30 \text{ days} \times 3 \text{ mm/day} = 90 \text{ mm of effective rainfall}$$

(Note: the 3 mm/day is approximately the free surface evaporation rate in mid-summer for the UK.)

Therefore, the area for which Interception can theoretically be delivered by a 1 m^2 vegetated surface, in a peak summer month is:

$$90/29 = 3 \text{ m}^2$$

The effectiveness of the vegetated surface will be less if the average evapotranspiration capacity is less. In wet periods (whether in mid-summer or at other times), compliance will be less than 100%.

This analysis assumes that all rainfall needs to be retained. In practice, there are a number of events that are greater than 5 mm and in these cases the soil would not be expected to retain all the runoff. If one assumes that 25% of the runoff does not need to be retained to make an allowance for these larger events, this increases the paved area ratio served from 3 to 4.

Where the method is being applied to SuDS components with side slopes (eg swales or detention basins), an allowance should be made for the effective wetted width (ie the width of the surface that would be wetted when conveying runoff for the 5 mm rainfall depth event), rather than just taking the base of the component. For example, although the base of a swale might only be 1 m wide, the effective wetted width might be considered to extend over another 1–2 m. This would increase the area served by the system.

Allowance should be made for the variability in the rainfall, so it is suggested that temporary storage of 50 mm of rainfall is needed in the soil store beneath the vegetated surface. Assuming 20% voids ratio, the depth of available soil needed is 250 mm. Water at depths > 250 mm is much less likely to be lost through evapotranspiration.

Infiltration (where the system is not specifically designed for this purpose)

Unless the vegetated surface is lined, there will usually be small amounts of infiltration taking place from runoff events. A rate of infiltration of 1×10^{-7} m/s (which is a nominal rate and would not be considered for infiltration design specifically) represents approximately 260 mm of infiltration per month.

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BOX 24.3 Simple approaches to Interception delivery and compliance assessment

When this infiltration rate is combined with the evapotranspiration rate in summer (see above), this amounts to a combined depth of 350 mm which, when compared to an effective runoff depth of 29 mm per month, means that the system can deliver Interception for a contributing area of around 12 times the vegetated area. As for evapotranspiration, consideration should be given to the actual wetted area over which infiltration might be considered to occur for small events in non-saturated soils, provided that the design of the component encourages runoff across the full area before discharge.

Research on Interception by Kellagher (2014) showed that factors well in excess of 25 could be achieved using temporary storage depths (< 100 mm) above a 250 mm depth of well-prepared engineered soil and the use of marginal infiltration soil capacities. It can be seen that the infiltration rate is a crucial value for the analysis, so site testing should be undertaken to provide some justification of the rate assumed.

Wherever marginal infiltration is used to deliver Interception, the guidance on appropriate risk management design for Interception to protect groundwater should be followed (**Section 26.7**).

TABLE 24.6 Interception mechanisms

Systems	Interception methods that can be assumed to be compliant for zero runoff from the first 5 mm rainfall for 80% of events during the summer and 50% in winter
Green roofs	All surfaces that have green roofs
Rainwater harvesting systems	All surfaces drained to RWH systems designed to BS 8515:2009+A1:2013 whether for surface water management or just water supply, provided the RWH system design is based on regular daily demand for non-potable water.
Soakaway or other infiltration system[2]	Areas of the site drained to systems that are designed to infiltrate runoff for events greater than a 1 month return period. Note: design of the infiltration system should be in accordance with **Chapters 14 and 25**.
Permeable pavements[2]	All permeable pavements, whether lined or not, can be assumed to comply, provided there is no extra area drained to the permeable pavement. Where the pavement also drains an adjacent impermeable area, compliance can be assumed for all soil types where the pavement is unlined, as long as the extra paved area is no greater than the permeable pavement area. Where the infiltration capacity of the ground below the pavement is greater than 1×10^{-6} m/s, up to 5 times the permeable pavement area can be added as extra contributing area. Where the permeable pavement also drains an adjacent impermeable area and is lined, compliance cannot be deemed to have been achieved and extra downstream Interception components will be required.[*]

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TABLE 24.6 Interception mechanisms

Systems	Interception methods that can be assumed to be compliant for zero runoff for the first 5 mm rainfall for 80% of events during the summer and 50% in winter
Filter strips/swales[2]	Roads drained by filters strips/swales, where the longitudinal gradient of the vegetated area is less than 1:100, are suitable for Interception delivery for impermeable surface areas up to 5 times the base of the vegetated surface area receiving the runoff. Components steeper than 1 in 100 cannot be deemed to provide Interception unless additional effective Interception design can be demonstrated. Any filter strip/swale that is unlined, has a gradient less than 1 in 100 and has an infiltration capability greater than 1 × 10^{-6} m/s can be assumed to comply with Interception for a contributing area up to 25 times the area, or a larger area where infiltration capacities and design characteristics allow. Interception cannot be deemed to have been provided for impermeable areas draining to a swale within 5 m from the swale outlet, unless the swale is flat and has a slightly raised outlet to create a temporary storage zone to encourage infiltration before runoff takes place. Greater loading ratios can be achieved by providing flat swales with greater temporary storage and infiltration, but these require detailed design, based on the use of appropriate continuous rainfall time series.
Infiltration trenches[2]	Roads drained by infiltration trenches can be considered to provide Interception.
Detention basins[2]	Areas of the site drained to detention basins with a flat unlined base (without specific provision for routing low flows directly to the outlet) can be assumed to comply, where the drained impermeable surface area is less than 5 times the vegetated surface area receiving the runoff for any soil type. The area of the basin that is assumed to contribute to Interception of runoff should be below the outlet level of the basin. Areas up to 25 times the base area of the basin can be assumed to meet Interception requirements where infiltration rates are greater than 1 × 10^{-6} m/s. Higher loading ratios can be achieved where specific provision is made for water being stored below the outlet pipe and higher infiltration rates exist. Where a basin is designed to infiltrate runoff, specific provision should be made for the upstream control of sediments to minimise risks of waterlogging, high maintenance costs and reduced component amenity value.
Bioretention areas and rain gardens[2]	Areas of the site drained to unlined bioretention components can be assumed to comply[1] where the impermeable surface area is less than 5 times the vegetated surface area receiving the runoff. They can be designed to deliver Interception for larger areas, where suitable infiltration capacity is available.
Ponds	Areas drained by ponds (with a permanent water pool that is effectively maintained by the outlet structure) are not assumed to deliver Interception.

Notes

1 Where individual components do not provide sufficient Interception for the area draining to them, Interception capacity can also be provided by downstream components. Detailed calculations will be needed to demonstrate compliance in this case.

2 Where these systems are unlined or designed for infiltration, appropriate consideration should be given to the adequate protection of groundwater (**Chapter 4, Table 4.3, and Section 26.7**).

24.9 DESIGNING FOR ATTENUATION STORAGE

24.9.1 General description

Attenuation storage is needed to temporarily store water during periods when the runoff rates from the development site exceed the allowable discharge rates from the site. Attenuation storage volumes are designed to drain at a rate controlled by the outlet structure.

Attenuation storage can be provided on site using structural controls (either above or below the ground surface), non-structural features and/or landscaped depressions. It can be provided by a storage component that is normally dry, or above a permanent water body – that is, a pond or wetland (**Figures 24.4 and 24.5**).

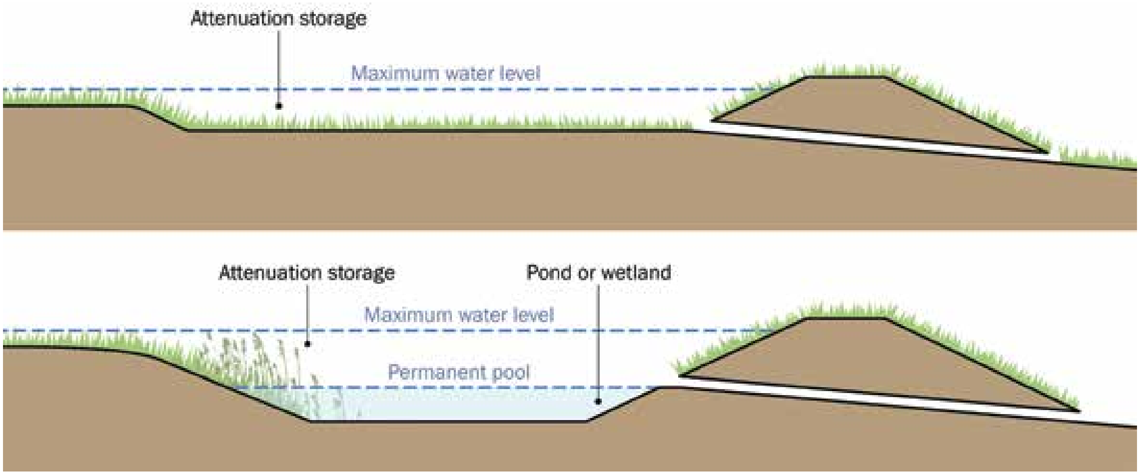

Figure 24.4 Attenuation storage in dry or wet components

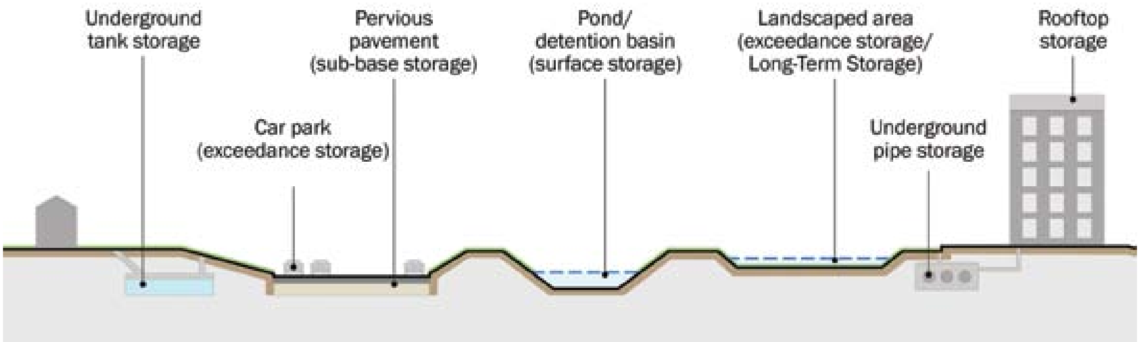

Figure 24.5 Examples of attenuation storage locations

Attenuation storage can be implemented either on line or off line. On-line storage uses a storage component through which all runoff from the upstream contributing catchment flows. Off-line storage is a storage component that is separate from the main drainage conveyance path, to which runoff is diverted when flow rates or levels exceed a threshold (**Figure 24.6**).

The advantage of off-line storage is that the volume of storage provided is minimised as the pass-forward flow rate is maximised before the storage starts filling. However, it does mean that the storage facility cannot combine as a treatment facility, as frequent events (that require treatment) will bypass the component and discharge directly downstream.

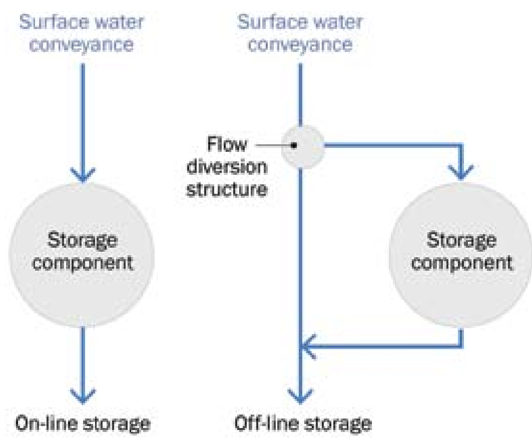

Figure 24.6 On-line vs off-line storage

24.9.2 Stage–storage design

A stage–storage curve defines the relationship between the depth of water and associated storage volume in a storage component. An example is given in **Figure 24.7**.

The storage can be estimated using Simpson's rule – a method for numerical integration (Atkinson, 1989). However, a less sophisticated approximation can be derived by averaging the areas for each height elevation over the full storage depth, and then integrating these – using **Equation 24.9**.

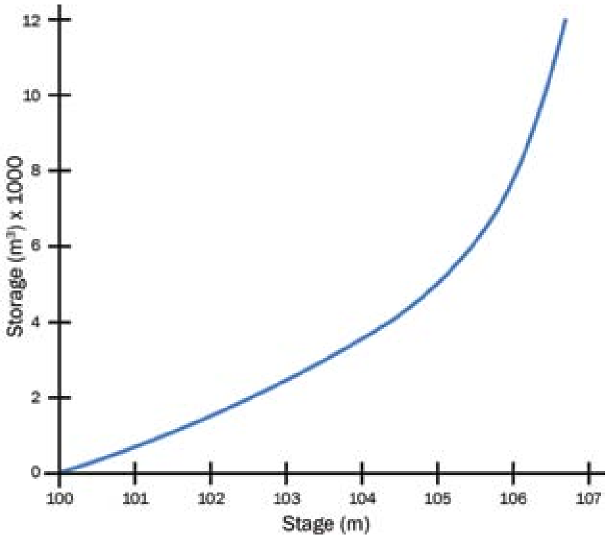

Figure 24.7 Example of a stage-storage curve

EQ. 24.9 Integration of storage volume from depth/area relationship

$$V_{1,2} = \left(\frac{A_1 + A_2}{2}\right) d$$

where:

$V_{1,2}$ = storage volume (m^3) between elevations 1 and 2
A_1 = surface area at elevation 1 (m^2)
A_2 = surface area at elevation 2 (m^2)
d = change in elevation between points 1 and 2 (m)

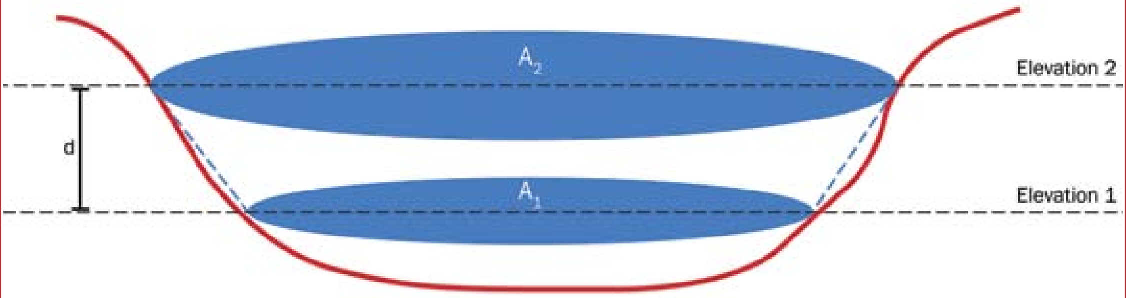

Figure 24.8 Schematic for estimating storage volume

24.9.3 Stage–discharge design

Simple outlet structures will only discharge at their maximum discharge rate at the maximum depth of water at which the water is stored. A stage–discharge curve (**Figure 24.9**) defines the relationship between the depth of water and the discharge or outflow from a storage facility. For simple assessments of storage requirements, this relationship can be accounted for by including a 25–30% extra storage allowance and using the design discharge flow rate. The relationship can be modelled explicitly using detailed simulation models.

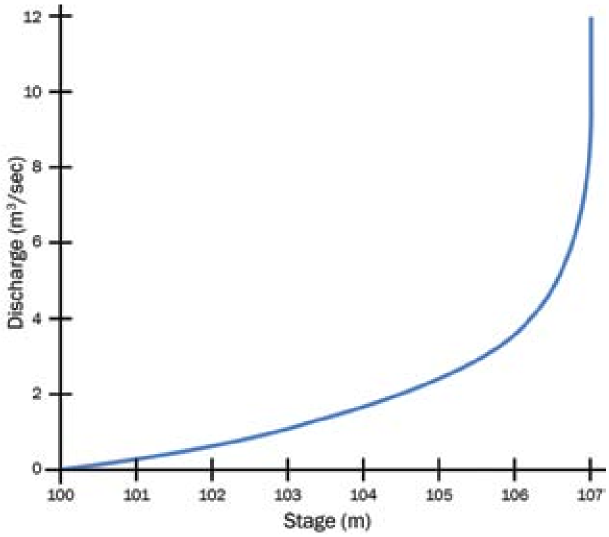

Figure 24.9 Example of a stage discharge curve

A storage component usually requires two outlets: a primary outlet and a secondary (or emergency) overflow route. A pipe, weir, orifice plate or other appropriate outlet is generally used for the principal outlet and an emergency spillway weir normally provides a bypass for floodwater for flows that exceed the design capacity of the component and as protection against blockage of the main outlet. The principal outlet may need to have a multiple flow control system, so that both 1:1 year and 1:100 year flow rates are adequately controlled. Guidance on the design of inlets and outlet controls is set out in **Chapter 28**.

24.9.4 Initial attenuation storage volume assessment

A method that gives an initial estimate of the required attenuation storage volume is provided in Kellagher (2013).

An alternative to the Kellagher (2013) approach is to develop a simple lumped simulation model of the storage system with a limiting discharge throttle and an overflow. The volume passing over the overflow is then the storage required for that specific event and throttle. A range of different storm durations will be required to determine the maximum spill volume. This method will underpredict the actual volume of storage needed as the head–discharge relationship for the hydraulic control is not being considered. Therefore, a further allowance of 25% should be applied to the first estimate of storage to allow for this approximation. An accurate model of the storage and conveyance system should be built at the earliest possible stage, to ensure that approximate estimates can be confirmed.

24.9.5 Detailed attenuation storage volume assessment

For most sites, a detailed model of the drainage system will be run at detailed design stage, with accurate depth storage and head discharge relationships represented accurately. This will enable checks to be made of the discharge rate controls and the adequacy of the proposed storages.

24.10 DESIGNING FOR LONG-TERM STORAGE

24.10.1 General description

Additional runoff volumes from developments can cause increases in flood risk downstream of the site, even where peak flows from the site are controlled to greenfield rates (**Section 3.1.2**).

Therefore, for extreme events, in addition to the standard for controlling the peak rate of runoff, there is also a standard that requires runoff volume control for the 1:100 year, 6 hour event (**Section 3.3.1**). This is particularly critical for catchments that are susceptible to flooding downstream of the proposed development.

The difference in runoff volume between the development state and the equivalent greenfield (or possibly pre-development state where this is considered to be acceptable) is termed the Long-Term Storage Volume. It is this volume that should be prevented from leaving the site (via rainwater harvesting and/or infiltration) or, where this is not possible, controlled so that it discharges at very low rates that will have negligible impact on downstream flood risk. Only the greenfield (or pre-developed) runoff volume should be allowed to discharge at greenfield (or pre-developed) rates.

Where there is extra volume generated by the development that has to be discharged (because there are no opportunities for it to be infiltrated and/or used on site), this volume should be released at a very low rate (eg < 2 l/s/ha or as agreed with the local drainage approving body and/or environmental regulator) and the 1:100 year greenfield allowable runoff rate reduced to take account of this extra discharge (Kellagher, 2002).

An alternative approach to managing the extra runoff volumes from extreme events separately from the main drainage system is to release all runoff (above the 1 year event) from the site at a maximum rate of 2 l/s/ha or Q_{BAR}, whichever is the higher value (or as agreed with the drainage approving body and/or environmental regulator). This avoids the need to undertake more detailed calculations and modelling.

Kellagher (2002) demonstrates that if discharges are not limited to less than 3 l/s/ha, the drainage system will generally not be effective at retaining sufficient water on the site to prevent an increase in flood risk in the receiving catchment. A discharge limit of 2 l/s/ha (or Q_{BAR}, which allows for higher discharge rates for specific soil types) has generally been accepted as an appropriate industry standard in the UK, unless alternative site or catchment specific limits are agreed based on local risk evaluation.

24.10.2 Greenfield sites: LTS volume estimation

A simple approach to the calculation of Long-Term Storage Volume is provided in Kellagher (2013) and set out in **Equation 24.10**. This approach uses a fixed percentage runoff for pervious surfaces defined by SPR.

The formula allows assumptions to be made as to whether some or all of the paved and pervious areas contribute runoff. The formula assumes that only 80% (ie the 0.8 coefficient in the equation) runoff occurs from paved areas, but 100% runoff can be assumed if it is felt that a more conservative assumption is needed. The pervious surfaces are assumed to have the same runoff coefficient before and after development. However, where sites are landscaped to prevent green areas contributing runoff or where pervious surfaces are likely to be heavily compacted following development, then adjustments to the coefficients can be made accordingly.

EQ. 24.10 **Estimating the extra runoff volume from a development site compared to the greenfield equivalent**

$$Vol_{xs} = RD \times A \times 10 \left[\frac{PIMP}{100}(\alpha\, 0.8) + \left(1 - \frac{PIMP}{100}\right)(\beta\, SPR) - SPR\right]$$

where:

- *Vol*$_{xs}$ = extra runoff volume of development runoff over greenfield runoff (m^3)
- *RD* = rainfall depth for the 1:100 year, 6 hour event (mm)
- *PIMP* = impermeable area as a percentage of the total area
- *A* = area of the site, in hectares (ha)
- *SPR* = SPR index for the SOIL or HOST class (specified as a decimal proportion; this specifies the proportion of runoff from pervious surfaces (if SPRHOST values are used, then the minimum value should be set to 0.1)
- α = proportion of paved area draining to the network (values 0–1) with 80% assumed runoff
- β = proportion of the pervious area draining to the network or directly to the river (values from 0 to 1)

If the paved area is assumed to drain to the network, and all the permeable areas are landscaped so that they do not enter the drainage system or river, Equation 1 simplifies to:

$$Vol_{xs} = RD \times A \times 10 \left(0.8\frac{PIMP}{100} - SPR\right)$$

However, where all the permeable areas are assumed to continue to drain to the river or network as well as all paved areas, Equation 2 becomes:

$$Vol_{xs} = RD \times A \times 10\ (0.8 - SPR)\frac{PIMP}{100}$$

The ReFH2 software can also be used to estimate the development and greenfield site runoff hydrographs using a dynamic estimate of percentage runoff (reflecting the evolution of soil water content for pervious surfaces during the event) (CEH and WHS, 2015). These hydrographs can then be compared to determine the difference in runoff volume.

Figures 24.10 and 24.11 illustrate the difference in runoff volume for the two extremes: fully disconnected pervious areas and fully connected pervious areas for the five different soil types, for any development density. By multiplying the x axis value by the catchment area and the rainfall depth, a storage volume can be derived.

These graphs demonstrate the very great impacts of different soil types, the importance of using infiltration to disconnect impermeable areas from the drainage network, and the need to be efficient in designing the general landscape to disconnect pervious areas.

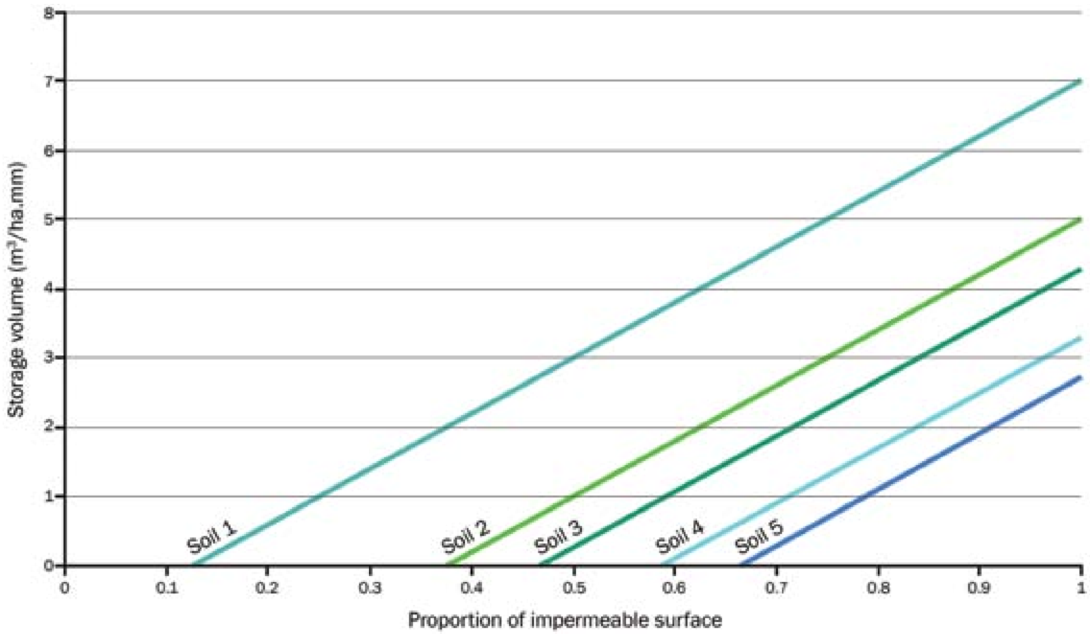

Figure 24.10 Difference in runoff volume for developments where all pervious areas are assumed not to drain to the drainage network

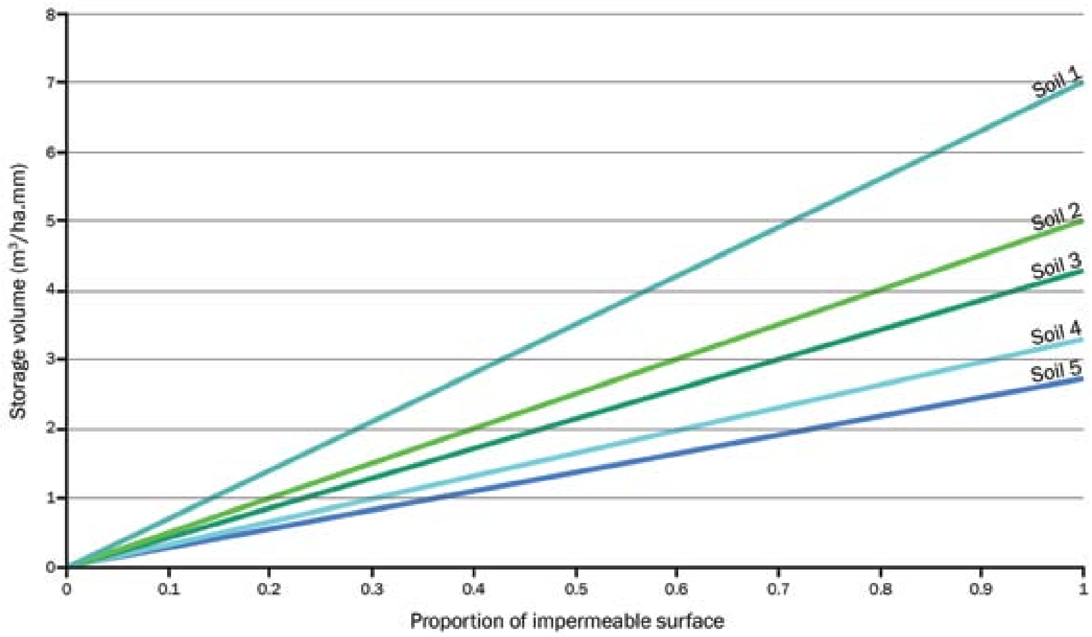

Figure 24.11 Difference in runoff volume for developments where all pervious areas are assumed to drain to the drainage network

24.10.3 Previously developed sites: LTS volume estimation

Where the environmental regulator or drainage approval body agrees that the runoff volume for a previously developed site can be constrained to the previously developed runoff volume (rather than greenfield), **Equation 24.11** can be used to determine the difference in runoff volume between the new and existing development scenario. The application of the equivalent approach within the ReFH2 software is described in the technical guidance document (CEH and WHS, 2015).

The use of this equation assumes that a positive drainage system can be demonstrated to be operational (**Section 24.5**).

EQ. 24.11 Estimating the extra runoff volume from a proposed development site compared to the previously developed site

$$Vol_{xs} = RD \times A \times 10 \left[(0.8 - SPR)\frac{PIMP_2}{100} + (SPR - 0.8)\frac{PIMP_1}{100} \right]$$

where:

Vol_{xs} = extra runoff volume of the proposed development runoff over the runoff volume from the previously developed site (m^3)

RD = rainfall depth for the 1:100 year, 6 hour event (mm)

A = area of the site (ha)

SPR = SPR index for the SOIL or HOST class (specified as a decimal proportion); this specifies the proportion of runoff from pervious surfaces (if SPRHOST values are used, the minimum value should be set to 0.1)

$PIMP_2$ = percentage impermeability of the proposed site

$PIMP_1$ = percentage impermeability of the previously developed site

24.10.4 The practicalities of delivering volumetric runoff control

Any approach that delivers a reduction in the volume of runoff from the site will help in minimising the volume of storage that requires attenuation and slow release. Runoff reduction approaches include the use of vegetation to prevent runoff from indirectly drained areas, infiltration (both where infiltration rates are considered suitable for standard infiltration design – **Chapter 25**) and also where infiltration rates are poor, but some runoff reduction can be assumed (**Section 24.8**), and rainwater harvesting (where designed to deliver surface water management – **Chapter 11**).

Volumetric control only has to be met at the 1:100 year return period. Up until that point, events need only be constrained to the peak greenfield discharge rates. In practice, particularly where the Long-Term Storage Volume at 1:100 year is likely to be large, some form of spill or discharge control will need to come into effect at return periods of 1:5 years or 1:10 years, in order to ensure that the full volume is captured for the 1:100 year event.

In order to design a drainage system to minimise storage requirements (and, therefore, the space allocated to it and associated cost), consideration should be given to the feasibility of designing the normal attenuation storage units to overflow into the Long-Term Storage area when large events occur. This requires careful consideration of levels, but it does allow the off-line storage to be a multi-functional space – that is, it can have a primary function (eg car park, agriculture, recreation or amenity area) and will only be required infrequently for surface water management.

The critical duration event for the on-line attenuation system may be less than 6 hours, but more likely it will be much longer (eg around 24 hours). This means that the design needs to take account of two event durations: the critical duration for the attenuation storage system and the 6 hour event, which for the 1:100 year return period should meet the greenfield volume discharge criterion.

Any space that has another primary function should be designed with the frequency, depth, duration and velocity of flooding as key considerations. For example, in the case of temporary car park flooding, a maximum depth of around 150 mm would probably be required to avoid damage to vehicles for any size of event. The allowable duration of flooding would be a function of what might be an acceptable level of risk and inconvenience. The impact of the effect of flooding (for instance, saturation of a football pitch for up to a week after the flooding occurs, or potential damaging effects of sediment on a pervious pavement) needs to be evaluated and mitigated. Local communities, site owners, operators and people who use or visit the area should understand the dual functionality of temporary flood storage areas.

Maintenance procedures should be put in place to ensure that the functionality of the area as a surface water management feature is never compromised and to rehabilitate the area following a flood. Effective emergency procedures should be put in place for when the area is likely to fill with water. The drain-down of the area may be by infiltration or by direct throttle control, but any solution should be practical and robust in coming into effect in a proper manner even though it only has to operate rarely. Where the discharge rate has to be very low, the outfall structure will need to be designed to reduce the risk of blockage.

24.11 CONVEYANCE DESIGN

The layout of the development site, particularly the roads and the drainage system, should be designed so that natural overland conveyance pathways are used to manage surface runoff, where appropriate. Modern developments often have terraced houses, and care over building orientation and position, landscape design and the creation of long barriers to floodwaters is needed to avoid increasing the risk of local flooding.

24.11.1 Surface conveyance systems

Surface conveyance systems, such as swales, channels and ditches, should be designed to convey the peak design flow rate. The return period normally specified is the 1:30 year event (ie this should be conveyed before overland flow is permitted), but this level of service might be either increased or reduced depending on the consequence of flooding at a location. Manning's formula can be used to check on the capacity of individual channels (**Equation 24.12**), but the easiest way of checking the system performance is to carry out hydraulic simulation modelling using Manning's or Colebrook–White equations.

Two-dimensional mesh models can be used to show the flow paths, depths and velocities across the site for the 1:100 year or larger events. As with channels, there is a need to use appropriate hydraulic roughness coefficients in the 2D models for the overland flows.

Note that as SuDS are both volumetric storage units and conveyance elements, flooding will occur at different points in the site for different selected storm durations.

EQ. 24.12 Manning's conveyance equation (from Chow, 1959)

$$Q = \frac{A\,R^{2/3}\,S^{1/2}}{n}$$

where:

Q	=	flow rate (m^3/s)
n	=	Manning's coefficient, a roughness coefficient dependent upon the channel characteristics ($m^{-1/3}s$)
S	=	overall slope of the channel (m/m)
R	=	hydraulic radius = A/P, where A is the cross-sectional area (m^2) and P is the wetted perimeter (m)

Values of Manning's coefficient "n" can be obtained from many standard text books. Recommended values for grass channels are presented in **Section 17.4**.

24.11.2 Pipe conveyance systems

Pipes are still likely to be required to provide some of the conveyance and drainage connectivity for a site. All pipe networks should conform to BS EN 752:2008, which specifies minimum pipe diameters and gradients. In general, pipes should be at least 150 mm in diameter, and these should not be laid on a slope that is flatter than 1 in 150. Where larger pipes are required, pipes can be laid at gradients using the inverse of the pipe diameter, so a 225 mm pipe can be laid at 1 in 225 or steeper and a 300 mm pipe at 1 in 300 or steeper. For pipes larger than 500 mm, gradients should not generally be flatter than 1 in 500 due to construction tolerances. Pipes and manufactured channel components should be sized to carry the maximum design event peak flow rate using product literature, pipe capacity tables or hydraulic simulation modelling. All pipe networks to be adopted should conform to the most up-to-date guidance from the relevant sewerage undertakers (at the time of publication these are WRc 2007, 2010 and 2012). Relevant building regulations should be referenced for specifications for drainage pipework serving single properties.

24.12 EXCEEDANCE DESIGN

Exceedance flow management on the site should be designed to mitigate the risks to people and property associated with:

1. rates of runoff exceeding the designed capacity of the drainage system (for both conveyance and storage components)
2. restrictions on outflows from the drainage system due to high levels in the receiving water body
3. system blockages or other failures.

Very high rainfall intensities can occur for short periods in the UK, and these can overwhelm pipe-based systems for brief periods. SuDS tend to have longer-duration critical events and can often absorb the impact of short thunderstorms much better than pipe-based systems, even though their return period may be high. However, in all cases, there will be events that cause flooding at points in the network if the event is severe enough and is of a relevant duration. The return period to use to evaluate these events is often limited to 1:100 years with a climate change factor. However, dam break risks, nuclear establishments or critical infrastructure all warrant evaluation of the impact of more severe (less frequent) events. The appropriate return period to use should be based on the implications of the consequence of such an event occurring. There are some sources of guidance on this, such as the application of the Reservoirs Act 1975 or the requirements of the nuclear industry, but in most cases this will be a matter for site specific determination.

Particular attention is needed on steep sites, due to focused flow paths and high velocities that might provide a scour risk or a hazard to people. Steep slopes also require attention in terms of modifying the runoff model, as saturated pervious areas can contribute rapid and high levels of runoff.

When the drainage system is overloaded, the surface water runs down to low points on the site. It is, therefore, important to consider this effect, and design the site layout and topography to adequately manage these flood risks. Although it is relatively easy to spot flood risk areas by examining the site contours and layout, the magnitude of flood ponding will be significantly influenced by the characteristics of the site and the drainage system. At the stage of initial evaluation, identifying the extent of flooding at these locations is difficult, as they can only be effectively determined using detailed simulation models.

Sites are particularly at risk during the construction period, as areas stripped of topsoil can act in a similar manner to paved surfaces and can generate very high rates of runoff, as well as contributing high levels of sediment and debris. This requires consideration when designing a temporary surface water management system and environmental protection during the construction phase, and when designing SuDS to manage scenarios where the development is being implemented in phases.

The design of exceedance flow management systems should therefore take account of:

- the location, use and capacity of exceedance flood pathways

- any low spots within the development that may act as temporary flood storage areas
- the location of properties and sensitive/critical infrastructure
- potential consequences of exceedance flows to people and/or property.

Surface flood conveyance paths or storage zones for extreme events should:

1 not detract from the primary function of the drainage system

2 be protected and maintained to ensure their continued availability as a flood management feature

3 include a freeboard allowance to allow for uncertainties

4 be designed so that flood depths and velocities are limited to acceptable levels both on site and downstream of it

5 not block pathways that the public would need to use to escape from flooded areas (usually only an issue associated with stream flooding or river floodplains).

Roads may be appropriate to use for storing flood water for brief periods of time on an infrequent basis, subject to their maximum traffic speed and designation. Roads should not be used to store water on a frequent basis or where the speed of the traffic is such that any stored water poses a potential accident risk.

Detail on designing for exceedance can be found in Digman *et al* (2006) and Digman *et al* (2014).

24.13 SURFACE WATER PUMPING STATION DESIGN

Where surface water management for the site cannot avoid the use of pumping, the pumping station should be designed in accordance with BS EN 752:2008. Where the pumping station is to be adopted by the sewerage undertaker, it should also be designed in accordance with WRc (2007, 2010 and 2012).

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British Standards

BS 8515:2009+A1:2013 *Rainwater harvesting systems. Code of practice*

BS EN 752:2008 *Drain and sewer systems outside buildings*

Image courtesy Leicester City Council

25 INFILTRATION: DESIGN METHODS

Contents

Chapter 25 Infiltration: design methods

This chapter provides guidance on the suitability of using infiltration to dispose of surface water runoff, infiltration testing and design methods.

- ▶ *Water quantity design criteria are set out in Chapter 3.*
- ▶ *Requirements for water quality management for groundwater protection are set out in Chapter 4.*
- ▶ *Hydrology and hydraulic design methods and calculations are presented in Chapter 24.*
- ▶ *Guidance on component sizing for water quantity and water quality management is provided in Chapters 11–23.*
- ▶ *Methods for meeting water quality management requirements are presented in Chapter 26.*

25.1 GENERAL CONCEPTS

Infiltration systems allow surface water runoff to infiltrate into the ground over a period of time, thus reducing the volume of runoff during a rainfall event. Infiltration systems can deliver Interception for the upstream contributing catchment surface (**Section 24.8**) and can also help reduce the attenuation storage volume requirements required for the site (**Section 24.9**).

The use of infiltration to dispose of surface water runoff also has a number of other important benefits:

- It can help replenish aquifers local to the site through deep infiltration and/or act to support local river base flows and wetland systems via shallow infiltration processes.
- It can help support local soil moisture levels and vegetation. In urban areas this may reduce the adverse effects that trees can have on foundations by reducing the potential for shrinkage of soils.

For a soil to be suitable for infiltrating design runoff events, it should be:

- permeable, and
- unsaturated.

Also, it should be of sufficient thickness and extent to disperse the water effectively. **Figure 25.1** is a schematic of a typical infiltration system.

There are a number of constraints to the use of infiltration. These should be fully evaluated for any site and any potential infiltration location, to ensure that risks are minimised (**Section 25.2**). The rate at which infiltration might occur – together with the design standard of service of the system and the contributing catchment area – will influence the area of the infiltration surface and the volume of temporary storage required. Guidance on establishing appropriate infiltration rates is set out in **Sections 25.2 and 25.3**.

For further detail on the hydraulic design of infiltration systems, see Bettess (1996).

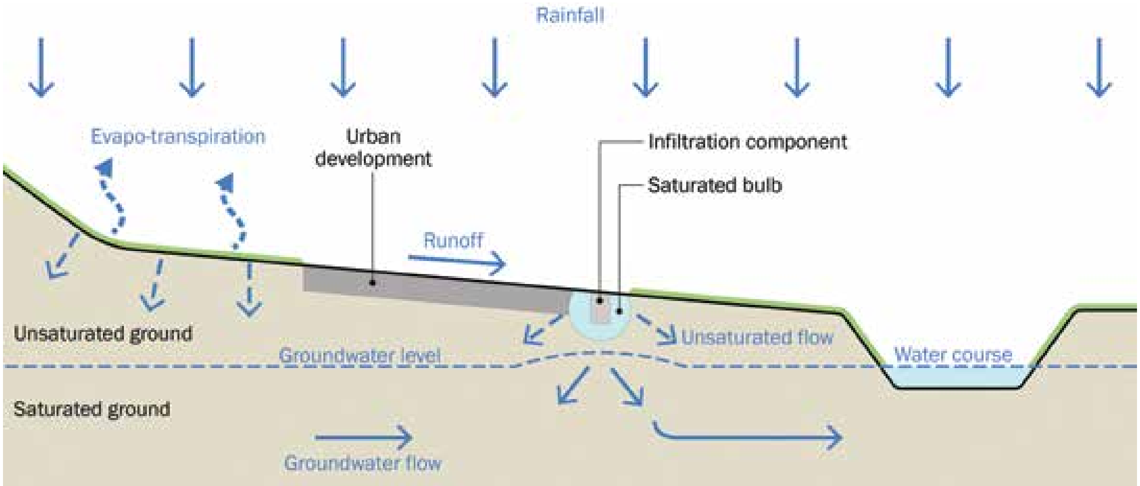

Figure 25.1 Typical surface water management infiltration system

25.2 EVALUATING POTENTIAL CONSTRAINTS TO THE USE OF INFILTRATION

The following considerations should be fully evaluated before determining the extent to which infiltration can be used on a site:

- soil type and infiltration capacity
- groundwater level beneath the site
- risk of ground instability, subsidence or heave due to infiltration
- risk of slope instability or solifluction (the slow creep of saturated soils down slopes) due to infiltration
- risk of pollution from mobilising existing contaminants on the site due to infiltration
- risk of pollution from infiltrating polluted surface water runoff
- risk of groundwater flooding due to infiltration
- risk of groundwater leakage into the combined sewer due to infiltration

Each of these is discussed in more detail in the following subsections.

Infiltration surfaces can be at or near the ground surface and spread over a wide area (eg basin), or at a point location (eg soakaway). The risks posed by infiltrating water to nearby structures and slopes or groundwater become greater the higher the ratio of the contributing catchment area to infiltration surface area. For example, large-volume deep soakaways are more likely to cause adverse effects than small shallow basins or infiltration from pervious surfaces.

Preliminary information on whether a site may be suitable for infiltration can be obtained from:

- existing geological and hydrogeological studies and mapping for the site
- geohazard mapping (eg the British Geological Survey infiltration SuDS map (BGS, 2015))
- records of potential contamination at or beneath the site
- borehole records or groundwater observations relevant to the site
- aquifer designations at or near the site.

Infiltration on sites where there is storage of potential pollutants (eg industrial sites with chemical storage) is likely to require an environmental permit. The acceptability of infiltration at any site and the design of risk mitigation measures is set out in **Chapter 4, Table 4.3 and Chapter 26**.

25.2.1 Infiltration capacity of the soils

The rate at which infiltration occurs depends on the properties of the soils and the underlying geology through which the water is discharged. The capacity of the soil to infiltrate water is given by the infiltration coefficient. This is the long-term infiltration rate into the soil divided by the area of infiltration. The infiltration rate is related to a soil's permeability.

The permeability of a saturated soil, *k*, is its ability to transmit fluid under a hydraulic pressure gradient. It is often called the coefficient of permeability or hydraulic conductivity. Darcy's law defines the flow per unit area under saturated conditions. Infiltration of water into soil above the water table will most likely be into partially saturated soils where the relationship between soil properties and flow is far more complex and is described by non-linear differential equations. Because of the difficulty in solving the equations, an empirical constant infiltration rate or coefficient, *q*, is used (derived from infiltration tests).

Where water is free-draining vertically in an unsaturated soil with a reasonably steady flow system it is reasonable to assume a unit hydraulic gradient (Watkins, 1995). Under these conditions the infiltration rate, *q*, is numerically equivalent to the soil coefficient of permeability, *k*.

Permeability or infiltration rate will be high for coarse-grained soils such as sands and gravels and low for fine soils such as silts and clays. However, it should be noted that in the UK, sand and gravel deposits often have a high silt or clay content, which will reduce their infiltration rate significantly.

Table 25.1 gives typical infiltration coefficients for different soil textures. Soil textures are defined by the proportion of different-sized particles as shown in **Figure 25.2**.

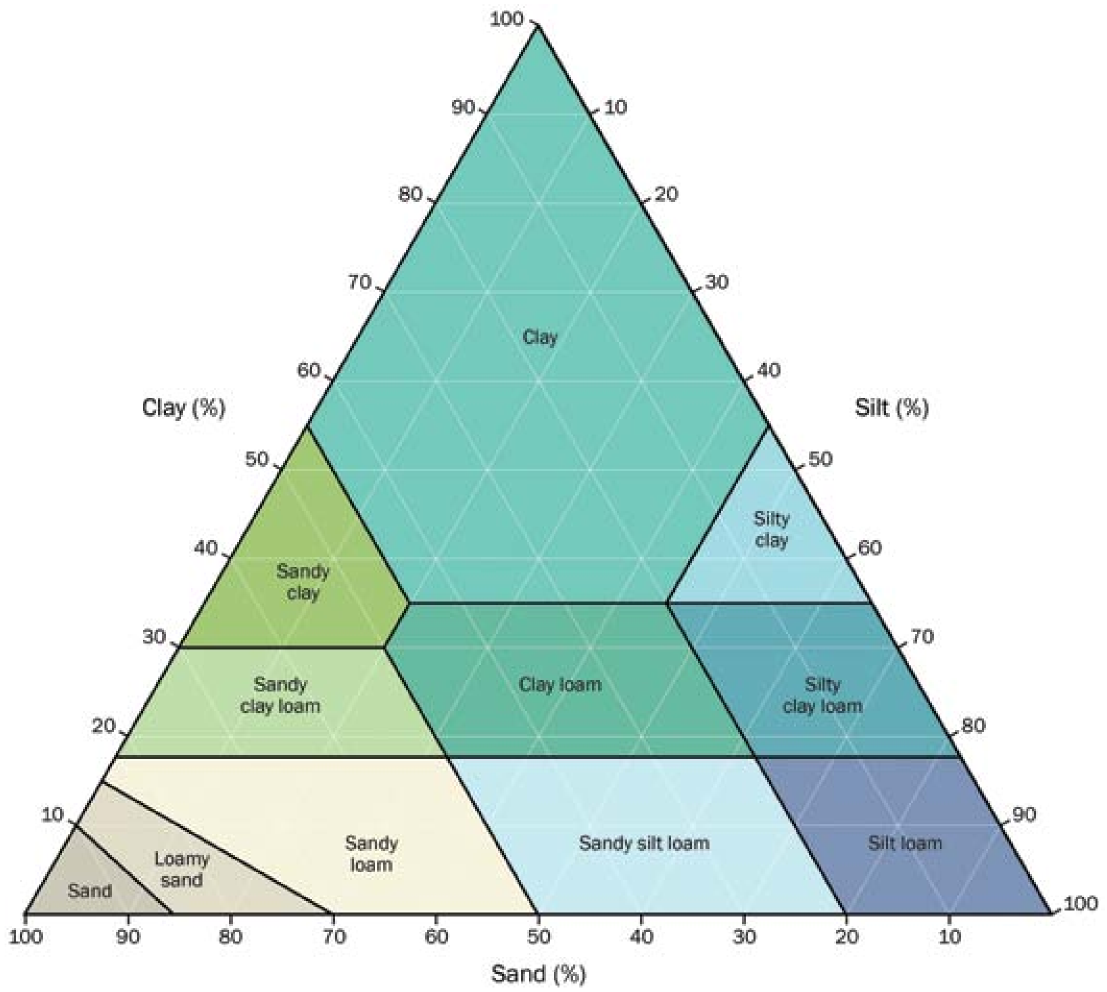

Figure 25.2 Soil texture classification (from LandIS, 2015)

This classification is different from the description systems used by geotechnical engineers in site investigation reports, which should follow BS ISO 14688-1:2002. Further information on the properties of soil that are important in infiltration design are provided by Blake (2010). This paper also discusses how increased groundwater levels can reduce the infiltration rate of soils and provides a reduction coefficient to allow for this effect in design.

The figures in **Table 25.1** provide a useful first indicator of the magnitude of the infiltration capacity, but the large ranges reported illustrate the significant influence of factors such as soil packing, soil structure, swelling clay content and the presence of bedding, jointing or other fissures in rock. Also, construction activities can severely affect infiltration rates if care is not taken to protect against compaction or blockage from fines. In some cases, infiltration of water into rock material can cause a reduction of infiltration capacity with time as the rock weathers. This is especially important with some fractured mudstones where initial high infiltration rates soon reduce as the rock softening and joints become infilled.

TABLE 25.1 Typical infiltration coefficients based on soil texture (after Bettess, 1996)

Soil type/texture	ISO 14688-1 description (after Blake, 2010)	Typical infiltration coefficients (m/s)
Good infiltration media		
▪ gravel	Sandy GRAVEL	$3 \times 10^{-4} – 3 \times 10^{-2}$
▪ sand	Slightly silty slightly clayey SAND	$1 \times 10^{-5} – 5 \times 10^{-5}$
▪ loamy sand	Silty slightly clayey SAND	$1 \times 10^{-4} – 3 \times 10^{-5}$
▪ sandy loam	Silty clayey SAND	$1 \times 10^{-7} – 1 \times 10^{-5}$
Poor infiltration media		
▪ loam	Very silty clayey SAND	$1 \times 10^{-7} – 5 \times 10^{-6}$
▪ silt loam	Very sandy clayey SILT	$1 \times 10^{-7} – 1 \times 10^{-5}$
▪ chalk (structureless)	N/A	$3 \times 10^{-8} – 3 \times 10^{-6}$
▪ sandy clay loam	Very clayey silty SAND	$3 \times 10^{-10} – 3 \times 10^{-7}$
Very poor infiltration media	–	
▪ silty clay loam	–	$1 \times 10^{-8} – 1 \times 10^{-6}$
▪ clay	Can be any texture of soil	$< 3 \times 10^{-8}$
▪ till	described above	$3 \times 10^{-9} – 3 \times 10^{-6}$
Other		
▪ rock* (note mass infiltration capacity will depend on the type of rock and the extent and nature of discontinuities and any infill)	N/A	$3 \times 10^{-9} – 3 \times 10^{-5}$

Therefore, field tests should always be undertaken in order to determine infiltration coefficients for design purposes. Infiltration testing is described in **Section 25.3**. Any testing should be as extensive as possible and supported by evidence of wider soil characteristics, in order to avoid misrepresentation of relevant soil properties. **Figure 25.3** illustrates an example of where local testing may not adequately characterise the soil horizons.

If infiltration is proposed at conceptual design stage and there are no infiltration test results available, alternative proposals for discharge should be provided. This will ensure that if infiltration tests show it is not possible, the site can still be effectively drained.

Infiltration viability should be given full consideration where rates of 10^{-6} m/s or greater exist on the site (subject to geotechnical and contamination considerations). Where rates are less than that, the soils can still usefully be used for Interception delivery, but disposal of significant volumes of runoff may not be cost-effective or appropriate, unless there is a large area of land available for this purpose.

It should be noted that Interception does not necessarily require any infiltration capacity, as it can also be delivered via green roofs, bioretention systems etc.

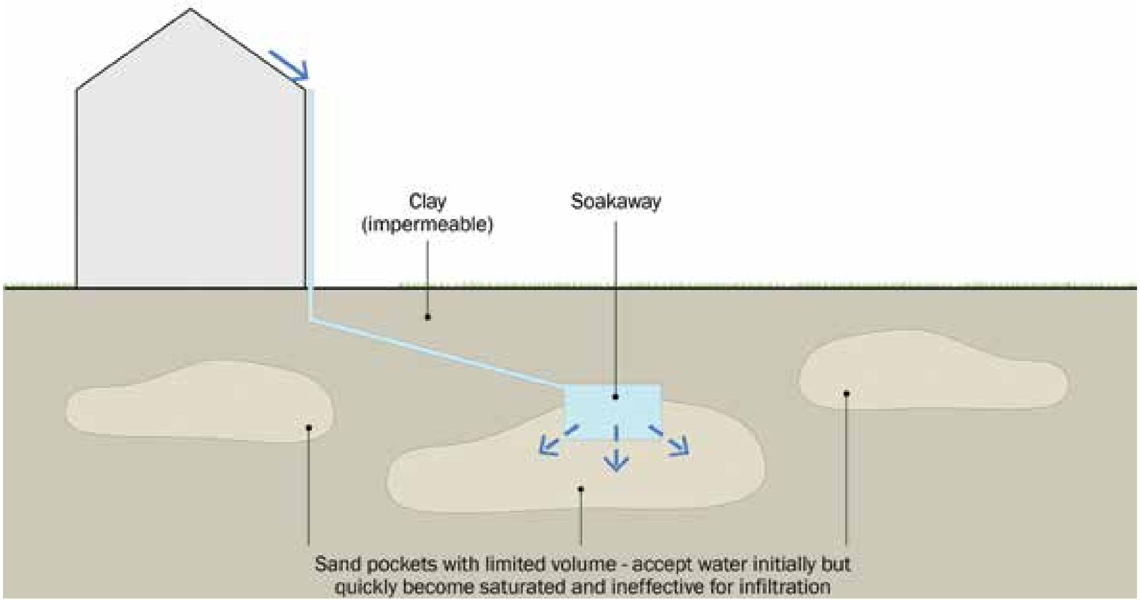

Figure 25.3 Local soil testing misrepresenting wider soil properties

25.2.2 Groundwater level

Groundwater levels should be investigated to ensure that the base of the proposed infiltration component is at least 1 m above the maximum anticipated groundwater level (taking account of seasonal variations in levels and any underlying trends). This should include assessment of relevant groundwater/borehole records, maps and on-site monitoring in wells. Guidance on the design of SuDS in areas with high groundwater is set out in **Section 8.3**. A 1 m separation distance ensures a depth of unsaturated soils to help ensure the infiltration performance of the component and protect underlying groundwater from contamination (**Section 25.2.5**).

25.2.3 Geohazards

Geotechnical advice should be taken and geotechnical properties of surrounding soils should be checked to ensure that the infiltration of water will not pose an unacceptable risk to the site and/or local area. It should be established that infiltration will not cause significant risk of instability (eg of retaining walls, slopes, solution features or loosely consolidated fill) or movement that could adversely affect any nearby buildings or other structures.

The potential risk of adverse effects from infiltrating water will depend on the volume of water being discharged along with the depth and plan area of the infiltration system. The smaller the area of the system in relation to the drained area, the greater the risk.

A geotechnical investigation is likely to be required to ensure that the ground conditions are suitable and to check the likely performance of the infiltration component. **Figure 25.4** provides a decision tree for the assessment of geohazards for infiltration system. Further guidance on the design of SuDS in areas with unstable soils or backfill is set out in **Sections 8.6 and 8.7**.

Where infiltration is proposed closer than 5 m to the foundations of buildings or structures (except for a permeable pavement that does not take any extra impermeable catchment such as the roof) this assessment should be approved by a suitably qualified professional such as a registered ground engineering adviser. The BGS infiltration SuDS map (BGS, 2015) is a useful source of information. Advice on small-scale infiltration closer than 5 m to buildings is provided on **www.susdrain.org**

Infiltration near slopes also requires careful assessment of the impact of the moisture on slope stability. Over time the infiltration can cause an increase in moisture content of the soils below the slope and lead to instability. This is especially important near to slopes that are marginally stable. Such slopes can include manmade slopes (eg cuttings or embankments) or slopes that are or have been subject to solifluction. Some local authorities have solifluction maps showing areas where this may be an issue.

Guidance on the design of SuDS on sloping sites is set out in **Section 8.4**. Further information on geotechnical issues relating to infiltration can be found in Bettess (1996).

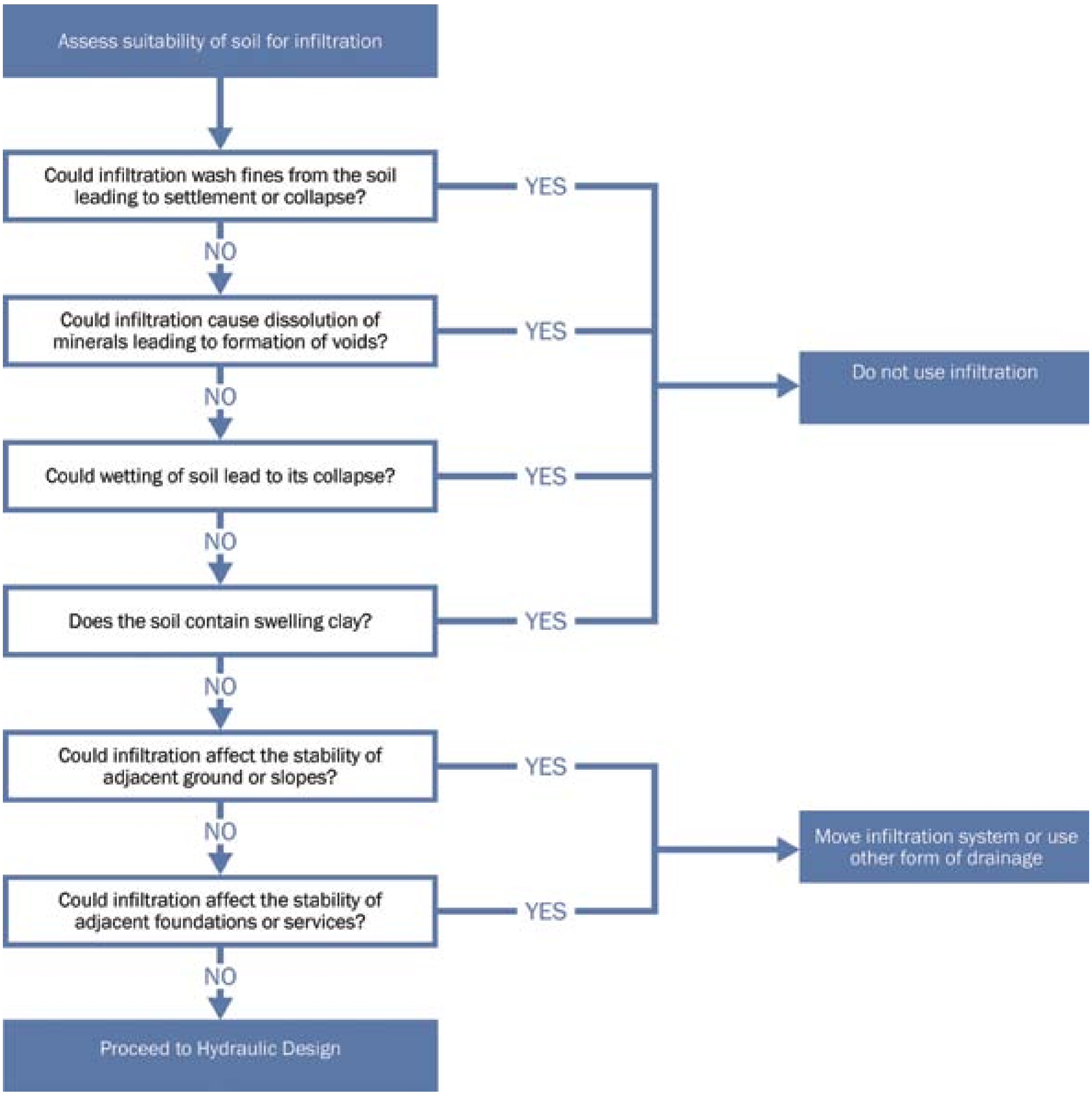

Figure 25.4 Decision guide for the use of infiltration systems

25.2.4 Site contamination

Infiltration can be used on many (but not all) contaminated sites. However, caution should be exercised when proposals include using infiltration methods on contaminated sites because they have the potential to cause pollution if the system is not carefully designed or managed. New pathways for pollutants to groundwater must not be created nor must contaminants be mobilised. Guidance on the design of SuDS for contaminated land sites is set out in **Section 8.2**.

An assessment of the potential for deterioration in groundwater quality due to infiltration (eg due to the mobilisation of contamination) should be undertaken before detailed design. This should consider the spatial and vertical distribution of contamination in relation to the location of infiltration devices and also the nature of the contaminants and whether they are mobile. Details of any remediation or contamination "sealing" strategies – either previously undertaken or proposed as part of the development site design – should be carefully evaluated.

All contamination evaluation assessments should be undertaken by a qualified geo-environmental engineer or similarly qualified person and may require a site investigation with contamination testing. The BGS infiltration SuDS map (BGS, 2015) can provide useful preliminary information.

25.2.5 Groundwater pollution

If the surface water runoff is polluted, there is a risk that infiltration systems may introduce pollutants into the soil and ultimately into the groundwater. Checks should be undertaken to confirm that the soils beneath any proposed infiltration component are suitable to provide adequate protection to the underlying groundwater. The SuDS design should also ensure adequate treatment of the runoff before infiltration. Requirements for water quality management for groundwater protection are set out in **Chapter 4**. Methods for meeting these requirements are set out in **Chapter 26**.

Any requirements for environmental permits should be checked before conceptual design stage (**Chapter 7**).

25.2.6 Groundwater flooding

An assessment should be undertaken of the potential effect of infiltration on groundwater levels local to any infiltration component and the potential wider impact of multiple infiltration components within the site, with respect to groundwater flood risk. The use of infiltration for steep sites can increase the risk of springs developing lower down the slope in layered geology/steep topography.

25.2.7 Groundwater/combined sewer interaction

An assessment should be completed of the risk of groundwater leakage into any local foul or combined sewers owing to introducing infiltration drainage. The risk of water infiltrating to a sewer will depend on the area of the base of the infiltration system compared to the catchment – for example, infiltration over the wide area of a pervious pavement that is only managing water that falls directly on it will be a low risk. Other factors to consider are the depth of soil between the sewer and the base of the infiltration device, horizontal separation and the age and likely condition of the sewer.

25.3 INFILTRATION TESTING METHODS

Infiltration tests should be carried out in accordance with Bettess (1996), which is based on the design approach in BRE (1991). The test measures the rate at which water soaks away from the test pit and gives an infiltration rate in m/s or m/h. It is important that the test is carried out in accordance with the report and that the test pit is filled three times. Repeating the test in this way can reduce the measured infiltration rate by at least half an order of magnitude each time the test is repeated, and is likely to reflect realistic event conditions as shown by the example in **Figure 25.5**.

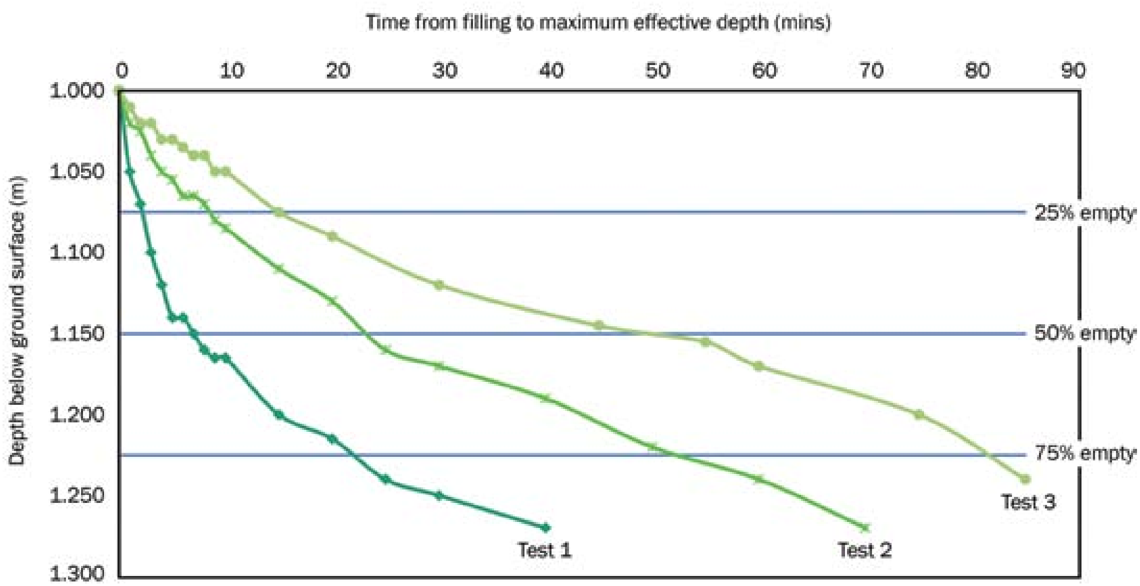

Figure 25.5 Example of reduction in infiltration rate with successive tests

In some cases it may not be possible to carry out tests in trial pits due to depth or access constraints. In this case, tests can be carried out in boreholes. The tests should follow the procedure in accordance with BS EN ISO 22282-2:2012. Falling head tests should still be repeated at least three times, as required in BRE (1991). Care should also be taken in the interpretation of the results, as a smaller volume of water is entering the ground during the test. Ideally, falling head tests should be repeated as many times as possible to increase the volume of water entering the ground.

One of the main risks to soakaway performance is inadequate infiltration testing, because of either time constraints at the planning stage or cost. If the water level in a test does not drop sufficiently quickly to do three tests in a day, it indicates low infiltration capacity and potential risks for long-term performance. However, the tests can be extended over two days using water-level loggers. If pits are left open overnight with water in them, then health and safety issues need to be addressed and as a minimum the areas will need to be securely fenced off.

The results of incomplete tests should not be extrapolated to obtain design values of infiltration rates. The head of water in the infiltration test should fall to less than 25% of the initial head of water. If this does not occur, the results should state that the infiltration rate cannot be determined. If other variations to the test method in Bettess (1996) are required, the test results sheet should clearly state what variations have been made to the test and why.

It is rare that sufficient tests are carried out on a site to allow statistical analysis. The worse-case infiltration rate value should be used (not the mean or any other value) unless a sound justification for doing otherwise is demonstrated.

Infiltration test results should always be provided together with trial pit records that include soil/rock descriptions of the materials in which the test has been completed in accordance with BS EN ISO 14688-1:2002 or BS EN ISO 14689-1:2003. The interpretation of the test results should be compared to the soil descriptions and any unusually high or low values assessed against the conceptual site ground model, and then confirmation should be provided that the measured infiltration rates are representative of the wider ground mass (eg the test has not been undertaken in a limited extent of sand within a mass of clay). The likely impact of water on the soil and the long-term infiltration rate should also be assessed.

The infiltration tests should be carried out at the location, depth and head of water that replicates the proposed design. For larger systems, the tests should provide sufficient coverage across the entire area to be occupied by the infiltration system. The test results sheet should state which stratum the results are appropriate to and any limitations in the test – for example, has the infiltration rate been estimated by assuming water only infiltrates into one particular stratum, such as a discrete layer of limestone?

25.4 THE IMPACTS OF SILTATION ON INFILTRATION SYSTEM PERFORMANCE

The soil surrounding an infiltration system can become blinded through ingress of silt, and the infiltration capacity reduced as a result. All infiltration system designs should therefore include appropriate pre-treatment (ie silt/sediment removal systems). Larger systems should also be monitored to check the extent or effects of long-term silt deposition if thought necessary – for example, by providing a monitoring well within the infiltration system that can be used to monitor the drop in water level after a rainfall event, or by providing access for visual inspection. Some blinding can be simply removed if there is access to the infiltration surface, but in other cases (eg deep soakaways) blinding can render the system useless over time. Even with upstream sediment protection it is likely that some silt will always collect in an infiltration device. The risk posed by silt depends on the relative difference in permeability between the silt and the surrounding soil, and on the design method used.

If the surrounding soil has similar permeability to the silt then there will be little effect. Also, if the design is based on the guidance in BRE (1991) then infiltration from the base is ignored and so any silt will also have negligible effect on infiltration rates (**Figure 25.6**).

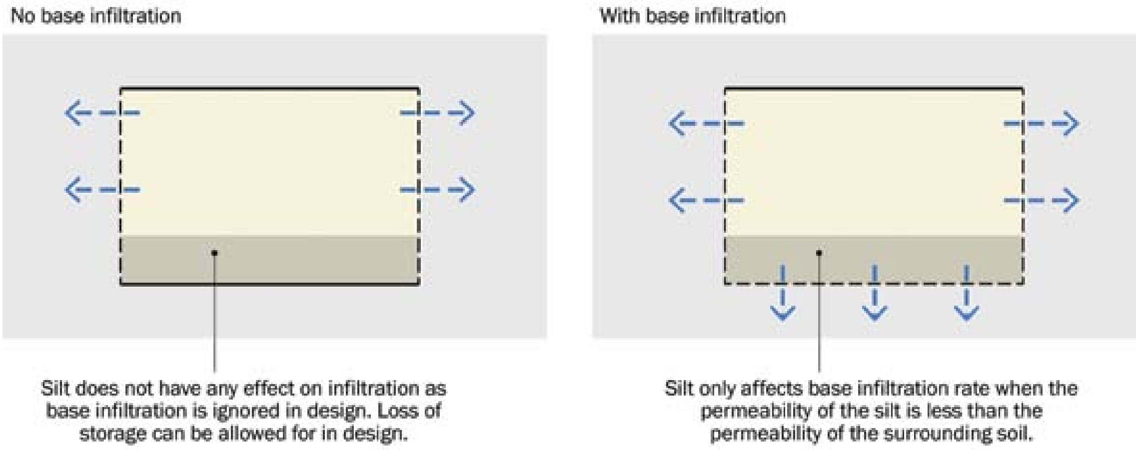

Figure 25.6 Effect of silt on performance of infiltration

There are many thousands of soakaways in the UK that have been working for over thirty years with no maintenance. This is probably because, in many cases, the infiltration capacity of the soil is relatively low in comparison with the accumulated silt, and so the reduction in capacity is marginal (Wilson and DeRosa, 2006).

The effects of siltation will be more noticeable when the infiltration rate of the soil is high in relation to that of the silt. Based on typical quoted gradings for silt, it is likely to have a permeability of around 1×10^{-6} m/s and, since many soakaways are designed using infiltration rates of around 1×10^{-5} to 1×10^{-6} m/s, the effects of the silt will be low. This points to the fact that care should be taken when assuming infiltration rates for design that are greater than 1×10^{-5} m/s, because, above this, the impact of silt on performance becomes more significant, especially where infiltration from the bottom of a systems is assumed (ie the design method in Bettess, 1996).

25.5 REUSE OF EXISTING SOAKAWAYS

Where sites are being redeveloped or extended, it may be possible to reuse existing soakaways. An approach for testing and assessing the capacity of existing soakaways is described by Chen *et al* (2008).

This method can be used to measure the performance and capacity of existing systems and examine whether the systems are suitable for reuse when design and construction details of the system are not available. Requirements for field observations and a procedure for a modified soil infiltration test performed within the system are proposed. The system's working condition is measured by a performance indicator related to the time taken to empty the soakaway. This is then employed to evaluate the potential reuse capacity of the system.

25.6 INFILTRATION SYSTEM HYDRAULIC DESIGN

In most circumstances, the area over which infiltration is proposed will be considerably smaller than the impermeable area being drained. Except for the most permeable of soils, the inflow rate to the infiltration system will exceed the outflow rate (the product of the infiltration coefficient of the soil and the infiltration area). It is therefore necessary to store the water on site or in the infiltration unit to allow time for it to soak away.

Provision of sufficient storage capacity is essential for an infiltration system to meet the design standard of service. The purpose of hydraulic design is to select dimensions for the system that are sufficient to store and infiltrate the runoff from the design storm. Overflows or additional discharge points should be provided, if total infiltration cannot be relied on for all return period events, and exceedance flow management should always be considered (**Section 24.12**).

The hydraulic design procedure is set out in **Figure 25.7**.

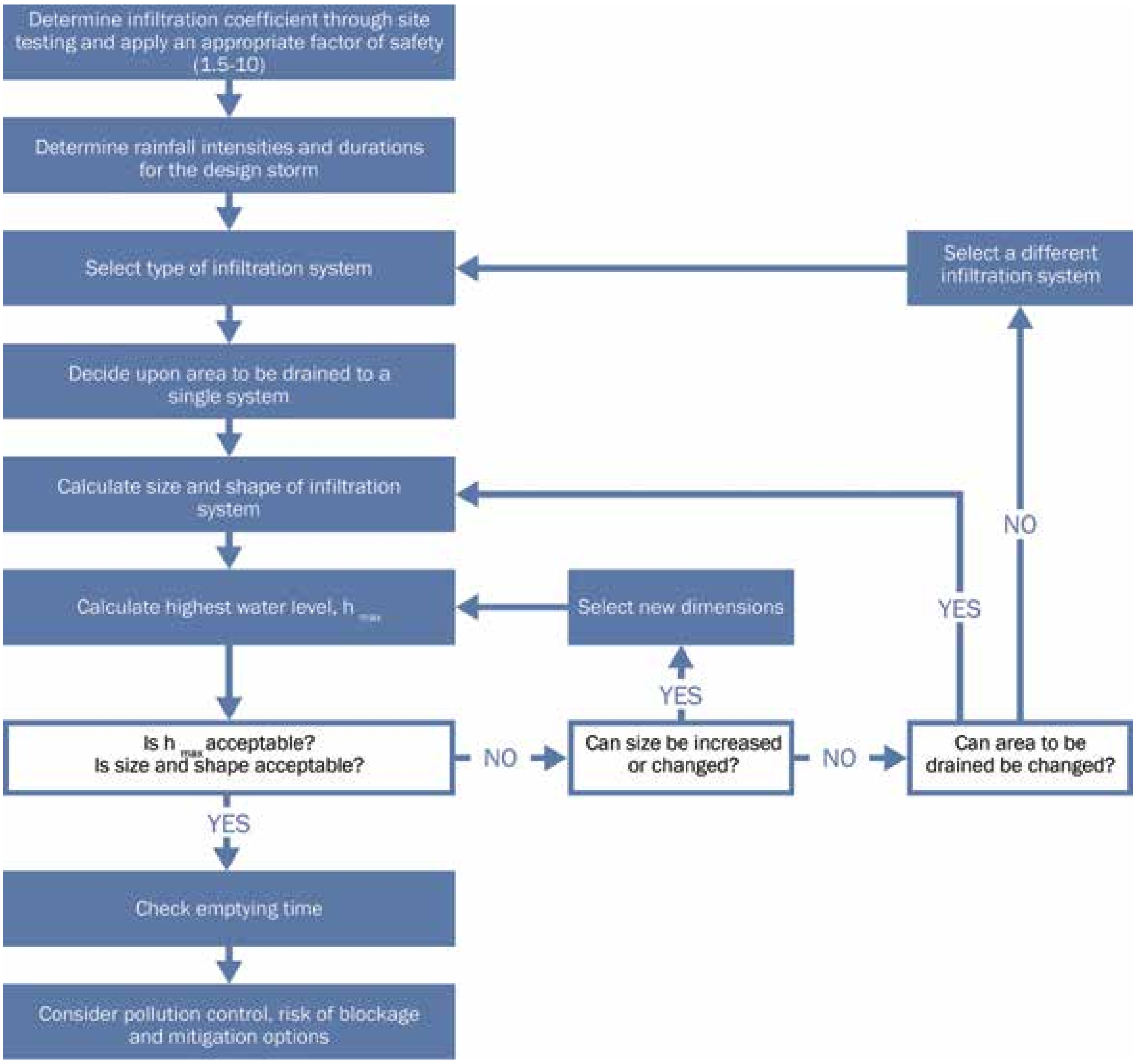

Figure 25.7 Hydraulic design process

Infiltration devices are commonly designed for return periods up to 1:100 year, plus an allowance for climate change. Advice on suitable return periods for specific components is provided in the relevant technical component chapters.

One of the largest uncertainties in the design of infiltration systems is the infiltration coefficient, as this may reduce over time, particularly if effective pre-treatment is not included within the design, and/or system maintenance is poor. To account for this, a factor of safety is introduced into the design procedure that reduces the observed value of the infiltration coefficient. The factor used depends upon the consequences of failure and engineering judgement is therefore required as to the factor to be used. Factors are suggested in **Table 25.2**. It should be noted that the figures are not based on actual observations of performance loss.

The following sections describe the calculation methods for infiltration system sizing.

25.6.1 Plane infiltration systems

Plane infiltration systems are relatively thin, and cover a wide area. The side area is negligible compared to the base area. For a given rainfall event discharging to an infiltration system of a particular size, the hydraulic equations can be solved to give the maximum depth of water, h_{max}. The equation for h_{max} is given in **Equation 25.1**.

TABLE 25.2 **Suggested factors of safety, F, for use in hydraulic design of infiltration systems (designed using Bettess (1996). Note: not relevant for BRE method)**

Size of area to be drained	Consequences of failure		
	No damage or inconvenience	Minor damage to external areas or inconvenience (eg surface water on car parking)	Damage to buildings or structures, or major inconvenience (eg flooding of roads)
< 100 m²	1.5	2	10
100–1000 m²	1.5	3	10
> 1000 m²	1.5	5	10

EQ. 25.1 **Determination of maximum depth of water for plane infiltration systems**

$$h_{max} = \frac{D\,(R\,i - q)}{n}$$

where:

h_{max} = maximum head of water above base of infiltration component

R = ratio of the drained area to the infiltration area, $R = \frac{A_D}{A_b}$

q = infiltration coefficient, from percolation test (m/h), adjusted by the appropriate factor of safety

i,D = intensity and duration of rainfall events with the required return period at the site location (m/h, h)

A_b = base area of infiltration system (m²)

A_D = area to be drained (m²)

n = porosity of fill material (voids volume/total volume)

This may be obtained from laboratory tests, or else the guide values provided in the following table may be used. If a value of porosity greater than 0.3 is used, the material delivered to site should be tested to ensure that it meets the design requirement.

Material	Porosity, *n*
geocellular systems	0.9–0.95
uniform gravel	0.3–0.4
graded sand or gravel	0.2–0.3

A perforated concrete ring soakaway may be installed in a square or rectangular plan excavation and the gap between the rings and the soil filled with clean stone. Under these circumstances an effective porosity, *n'*, applies.

$$n' = \frac{\pi(r')^2 + n[WL - \pi(r')^2]}{WL}$$

where

r' = radius of the ring sections (m)

W = width of the excavation (m)

L = length of the excavation (m)

EQ. 25.2 **Procedure for design of plane infiltration systems**

1. Obtain the infiltration coefficient, q, (m/h) by dividing the infiltration rate found from field tests by the appropriate factor of safety
2. Find the porosity of granular fill material
3. (i) Decide on the area to be drained, A_D,(m²) and the infiltration surface area, A_b (m²)
   (ii) Calculate the drainage ratio, *R*, where $R = \frac{A_D}{A_b}$
4. (i) Select a storm duration, *D* (h)
   (ii) Determine the corresponding rainfall intensity, *i* (m/h)
5. (i) Check whether q exceeds R_i. If so, the rate of infiltration exceeds the potential rate of runoff, in which case $h_{max} = 0$
   (ii) Otherwise, calculate the value of h_{max} (m)
6. Repeat steps 4 and 5 for a range of rainfall durations, constructing a spreadsheet or table of results
7. Select the largest value of h_{max}

The procedure set out in **Equation 25.2** will ensure that surface water runoff will be able to infiltrate through the lower surface of the system into the soil at the required rate. For systems such as infiltration basins or bioretention systems which have a surface layer of topsoil or filter soil, the rate at which water can percolate through the surface may be the limiting factor (**Chapter 13**).

For an infiltration pavement, R = 1, step 3 is omitted and the maximum depth of water is given by:

$$h_{max} = \frac{D\,(i-q)}{n}$$

For an infiltration pavement where no subgrade material is provided to allow short-term storage of water (ie open lattice blockwork), storage occurs on open ground above the infiltration surface. In this case *R* = 1, *n* = 1, steps 2 and 3 are omitted and the maximum depth of water is given by:

$$h_{max} = D\,(i-q)$$

Alternatively, for an infiltration blanket, the maximum depth h_{max} may be fixed, and the designer may wish to know the base area of the infiltration system that will be required to ensure that the depth of water does not exceed h_{max}, in which case the procedure given in **Equation 25.3** should be followed.

25.6.2 Three-dimensional infiltration systems

Three-dimensional infiltration systems are those that have a cuboid or trench shape, and the surface area of the sides is large compared to that of the base. For a given rainfall event discharging to an infiltration system of a particular size, the hydraulic equations can be solved to give the maximum depth of water, h_{max}. The approach used depends on whether the facility has vertical or sloping sides.

EQ. 25.3 **Procedure to determine the base area required for a given maximum depth**

The equation for the base area A_b (m²) is given by:

$$A_b = \frac{A_D\, i\, D}{n\, h_{max} + q\, D}$$

1 Obtain the infiltration coefficient, q, by dividing the infiltration rate found from field tests by the appropriate factor of safety

$$h_{max} = \frac{D\,(R\,i - q)}{n}$$

where R is the ratio of the drained area to the infiltration area, $R = A_D/A_b$

2 Find the porosity of granular fill material

3 (i) Decide on the area to be drained, A_D (m²)

(ii) Decide on the maximum allowable water level, h_{max} (m)

4 (i) Select a storm duration, D (h)

(ii) Determine the corresponding rainfall intensity, i (m/h)

5 (i) Calculate $A_D.i.D$, $n.h_{max}$, and $q.D$

(ii) Calculate A_b (m_2)

6 Repeat steps 4 and 5 for a range of rainfall durations constructing a spreadsheet or a table of results

7 (i) Find the largest infiltration surface area required

(ii) If this area is unacceptably large then increase h_{max} or decrease A_D and repeat from step 3

Vertical-sided structures

This procedure can be applied to soakaways and infiltration trenches. The maximum water depth h_{max} in the infiltration system is given in **Equation 25.4** and the procedure in **Equation 25.5**.

These equations can be solved computationally, or graphically using **Figure 25.8**.

EQ. 25.4 **Determination of maximum depth of water for 3D infiltration systems**

$$h_{max} = a\left[e^{(-bD)} - 1\right]$$

Where:

$$a = \frac{A_b}{P} - i\,\frac{A_D}{P\,q}$$

P = perimeter of the base of the infiltration system (m).

$$b = \frac{P\,q}{n\,A_b}$$

EQ. 25.5 **Procedure for design of 3D infiltration systems**

1 Obtain the infiltration coefficient, *q*, by dividing the infiltration rate found from field tests by the appropriate factor of safety

2 Find the porosity of granular fill material; if the structure is open, *n* = 1, but if it is part-filled with gravel then the effective porosity, *n'*, is used

3 (i) Decide on the area to be drained, A_D

(ii) Choose the type and shape of infiltration system, ie cylindrical soakaway, infiltration trench

4 (i) Select the proposed dimensions for the infiltration system, ie the radius of a cylindrical soakaway, the width and length of a rectangular plan system

(ii) Calculate the base area, A_b, and the perimeter, *P*, of the soakaway base from the proposed dimensions

(iii) Determine the value of *b* from $b = \frac{P\,q}{n\,A_b}$

5 (i) Select a storm duration, *D*

(ii) Determine the corresponding rainstorm intensity, *i*

6 Determine the value of *a* from $a = \frac{A_b}{P} - i\frac{A_D}{P\,q}$

7 Either calculate h_{max} or read off the value of h_{max} from **Figure 25.8**

8 Repeat steps 5 to 7 for a range of rainfall durations

9 (i) Find the largest value of h_{max}

(ii) If hmax is unacceptably high, return to step 4 and increase the dimensions

(iii) If h_{max} is still unacceptably high, either:

(a) return to step 3(i) and reduce the area drained to an individual system

or

(b) return to step 3(ii) and choose a different type of system

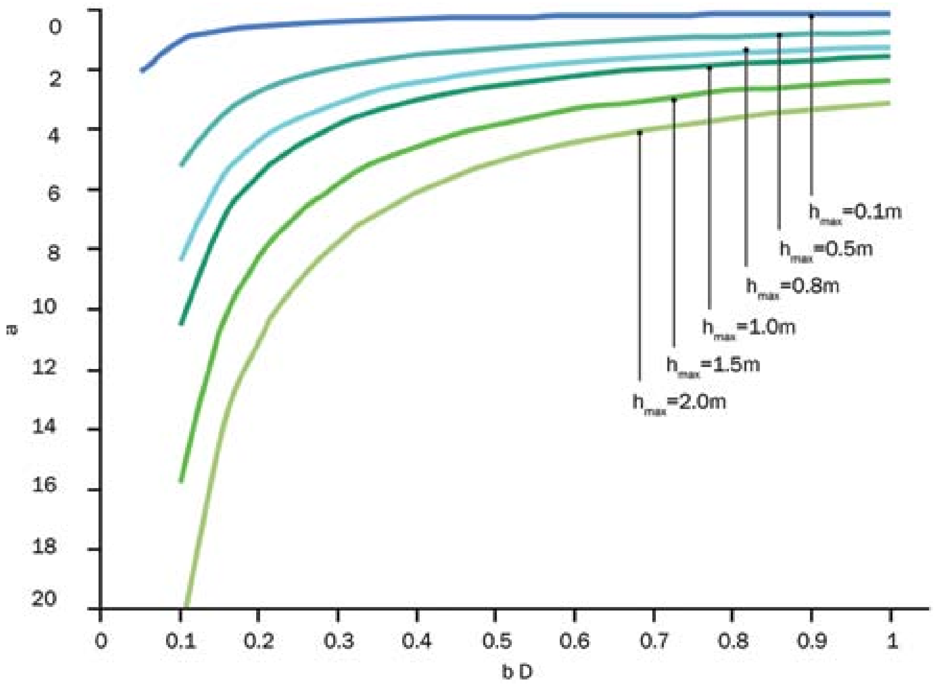

Figure 25.8 Graph to determine maximum depth for 3D infiltration systems (from Bettess, 1996)

Sloping-sided structures

For sloping-sided structures, there is no simple analytical method for calculating the maximum water depth. A numerical procedure for calculating the depth is given in Bettess (1996). It is recommended that sloping-sided structures are approximated by a vertical-sided structure or that the method described in that publication is used.

25.7 EMPTYING TIME CHECKS

The hydraulic equations in **Section 25.6** take both storage and infiltration into account and, if the infiltration rate is low, will ensure that the system incorporates sufficient storage. However, if infiltration is too low, there is the possibility that the system will not have emptied before the next rainfall event starts.

The infiltration component should discharge from full to half-full within a reasonable time so that the risk of it not being able to manage a subsequent rainfall event is minimised. Where components are designed to manage the 1:10 year or 1:30 year event, it is usual to specify that half emptying occurs within 24 hours. If components are designed to infiltrate events greater than the 1:30 year event, designing to half empty in 24 hours can result in very large storage requirements and, with agreement from the drainage approving body, it may be appropriate to allow longer half emptying times. This decision should be based on an assessment of the performance of the system and the consequences of consecutive rainfall events occurring.

Where emptying times are found to be too long, extra storage may be required (see **Equation 25.6**).

EQ. 25.6 **Equations to calculate the time to empty an infiltration system**

1 Time for half-emptying a plane infiltration system:

$$\frac{n\,h_{max}}{2q}$$

If the time for half-emptying is stipulated to be less than 24 hours and *q* is measured in m/h, then an acceptable infiltration coefficient is determined by:

$$q \geq \frac{n\,h_{max}}{48}$$

2 Time for half-emptying a 3D infiltration system.

$$\frac{n\,A_b}{q\,P}\,log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right]$$

If the time for half-emptying is stipulated to be less than 24 hours and *q* is measured in m/h, then an acceptable infiltration coefficient is given by:

$$q > \frac{n\,A_b}{24P}\,log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right]$$

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STATUTES

British Standards

BS EN ISO 14688-1:2002+A1:2013 *Geotechnical investigation and testing – identification and classification of soil. Part 1: identification and description*

BS EN ISO 14689-1:2003 *Geotechnical investigation and testing. Identification and classification of rock. Part 1: Identification and description*

BS EN ISO 22282-2:2012 *Geotechnical investigation and testing. Geohydraulic testing. Water permeability tests in a borehole using open systems*

Image courtesy HR Wallingford

26 WATER QUALITY MANAGEMENT: DESIGN METHODS

Contents

Chapter 26

Water quality management: design methods

This chapter provides guidance on the methods that should be used to design SuDS to meet the water quality design criteria and good practice design standards. This includes: the types of contaminants found in urban runoff; the treatment processes within SuDS components and the performance of different types of SuDS components; methods for evaluating the pollution hazard from different types of land use and the level of treatment required; designing a treatment system using the SuDS Management Train approach.

- *Water quality design criteria are set out in Chapter 4.*
- *Guidance on component sizing for water quantity and water quality management is provided in Chapters 11–23.*
- *Chapter 24 provides guidance on sizing storage and conveyance systems to deliver the water quantity design criteria.*
- *Chapter 25 includes further guidance on the suitability of using infiltration to dispose of surface water runoff.*

26.1 INTRODUCTION

Managing the quality of surface water runoff so that receiving surface waters and/or groundwater are protected is strongly linked to the hydraulic control of runoff. For the majority of cases, with well-designed SuDS, treatment and pollution removal can be delivered cost-effectively hand in hand with conveyance, attenuation and infiltration, particularly within vegetated surface-based systems.

Any SuDS component should be designed according to the guidance set out in the technical component chapters of this manual (**Chapters 11–23**), to ensure that treatment processes are effective.

26.2 PROTECTING SURFACE WATERS

Wherever possible, when discharging runoff from the site to surface waters, SuDS should be designed to intercept (ie prevent) runoff (and the associated pollutants) for most rainfall events up to approximately 5 mm in depth (see water quality standard 1 in **Chapter 4**).

When runoff does occur, treatment within SuDS components is essential for frequent rainfall events, for example up to about a 1:1 year return period event, where urban contaminants are being mobilised and washed off urban surfaces, and the aggregated contribution to the total pollutant load to the receiving surface water body is potentially high.

For rainfall events greater than approximately the 1:1 year event, it is likely that the dilution available in receiving surface waters will be significant, and environmental risks will be reduced, which means that SuDS treatment processes become less crucial. It may, therefore, be efficient to spill higher flow events from the main on-line treatment components into larger off-line conveyance and attenuation systems.

It is important that the SuDS design seeks to minimise the risk of remobilisation and washout of any pollutants that have been captured by the system during events larger than those for which the treatment system has been designed.

26.3 PROTECTING GROUNDWATER

The requirement for groundwater pollution risk management varies in different countries of the UK owing to different environmental regulators.

In England and Wales, the requirement for groundwater pollution risk management needs to be considered for all scales of runoff event, that is, for both:

- Interception of runoff (ie storing runoff in the upper soil layers of SuDS components from where small amounts of water may infiltrate, but where the component is designed as a storage or conveyance system rather than an infiltration system), and
- infiltrating significant volumes of runoff into the ground.

Advice on groundwater protection for England and Wales is provided in GP3 (Environment Agency, 2013).

In Scotland and Northern Ireland, groundwater pollution risk management is only required for SuDS components designed specifically for infiltration (eg soakaways, infiltration trenches or infiltration basins).

Advice on groundwater protection for Scotland and Northern Ireland is set out in SEPA (2009) and EHS (2001) respectively.

At the time of writing, the way in which Northern Ireland's groundwater protection policy is applied and integrated into SuDS policy development is under consideration, and the guidance in this manual should therefore be considered interim, until Northern Ireland specific policy is available.

The risk posed by surface water runoff to groundwater is often low because of the protection afforded by the layers of unsaturated soils that lie between the infiltration surface and the groundwater receptor. The effectiveness of the protection will depend on:

- the depth of the groundwater: a greater depth of unsaturated soil will tend to provide greater protection
- the predominant flow type, that is whether the flow occurs between soil grains (intergranular flow) or through larger channels (fracture flow): intergranular flow will tend to provide greater protection
- the soil characteristics: those with significant clay mineral and organic content have been demonstrated to offer increased potential for beneficial contaminant attenuation; similarly soil pH affects the mobility of contaminants, low pH soils being generally associated with more mobile contaminants.

The risk will also be dependent on:

- the runoff pollutants, their concentrations and how readily they can be degraded
- the volume of water infiltrated into the ground
- the length of time over which contaminants accumulate.

These factors will dictate the loading of contaminants on the soil, the rate of build-up, the capacity of the soil to retain pollutants and the point at which pollutants are likely to migrate to the groundwater.

Where the risks to groundwater are considered to be unacceptable, upstream (lined) SuDS components can often be used to reduce pollutant levels. If the risk is still considered unacceptable, infiltration should be prevented.

26.4 THE LEVEL OF POLLUTION IN SURFACE WATER RUNOFF

Evidence showing the extent to which surface water runoff is likely to be contaminated is summarised in Annex 1 – presented as a series of tables for selected pollutants. The tables include relevant environmental standards in an attempt to evaluate the likely significance of the measured pollutant concentrations (EA, 2014).

Although there is significant variability in the data presented, the data (particularly that from the UK) shows that surface water runoff from urban areas is polluted and demonstrates the potential need for pollutant levels to be reduced in order to meet environmentally acceptable levels.

26.5 TREATMENT PROCESSES WITHIN SUDS

There are a range of water quality treatment processes that can be exploited within the design of a sustainable drainage system – for example, sedimentation, filtration and biofiltration, separation, adsorption, biodegradation, volatilisation, precipitation, hydrolysis, oxidation, reduction and substitution, plant uptake and photolysis. These are presented in Annex 2.

Treatment effectiveness is strongly linked to the hydraulic control of runoff, in particular:

- **velocity control:** sediment deposition, filtration and other removal processes occurring at low flow velocities during regular rainfall events (ie through the control of velocities in SuDS components during frequent events, such as up to approximately the 1:1 year return period event)
- **retention time:** the removal of contaminants through settling, adsorption and other removal processes occurring (for events up to approximately the 1:1 year return period) over the period of time that the runoff is in contact with SuDS treatment media (eg the surface of a swale, the filtration media within a bioretention system) or held within a permanent water storage volume (eg pond).

It is also heavily dependent on the characteristics of any media through which the runoff filters.

26.6 EVIDENCE RELATING TO MANAGING WATER QUALITY RISKS

26.6.1 The capability of SuDS to reduce pollution levels

A relatively small number of monitoring studies of SuDS performance have been undertaken in the UK, but those that do exist confirm the benefit of SuDS in reducing levels of contamination in surface water runoff (Royal Haskoning, 2012, Woods Ballard *et al*, 2005, Jefferies, 2004, Jefferies and Napier, 2008, and Jefferies *et al*, 2008).

▶ Further guidance can be found at **http://sudsnet.abertay.ac.uk/downloads.htm**

The limited number of studies together with the lack of a consistent monitoring specification between studies mean that these datasets cannot be used alone to derive generic performance levels of different SuDS components. However, the stormwater BMP database <**www.bmpdatabase.org**> developed in the USA has grown to over 530 monitoring sites and has resulted in improved understanding of component performance in reducing contaminant concentrations to levels that should not pose a risk to the receiving environment (Leisenring *et al*, 2014). Recently, the project has also been extended to analyse performance of "manufactured devices". This concluded that performance levels can be comparable with vegetated components, but that manufactured devices only remove the pollutants for which they are designed, for their specified range of design flows. For example, sediment and particulate-bound pollutants may be removed by sedimentation, but dissolved constituents may require adsorptive filtration or some type of biochemical process to be removed effectively. It should be noted that SuDS performance is generally observed in terms of inflow and outflow concentrations of surface flows, rather than concentrations in underlying soil moisture or groundwater.

Table 26.13, Annex 1 summarises the data and includes a comparison with relevant water quality standards. It is recognised that the climatic conditions in the USA may result in different performance levels from the UK. However, in the absence of more robust data in the UK, the BMP database provides a useful indication of the range of outflow concentrations that may be achievable from a range of different components (confirming the capability of SuDS to reduce concentrations to more environmentally acceptable levels) and the potential variation between component types.

Key generic findings with respect to the removal of TSS and metals are summarised in **Box 26.1**.

BOX 26.1 Generic findings regarding the removal of TSS and metals

Total suspended solids
In general, sediment removal tends to improve as hydraulic residence time increases. This can be increased in ponds, wetlands and basins by increasing flow path lengths. In filters and bioretention system, increasing bed thickness and evenly distributing flow would improve performance. For infiltration components, maintenance is critical to prevent clogging from sediment build-up. Designing to minimise scour and resuspension of deposited sediment is important, along with ensuring appropriate long-term maintenance to remove accumulated sediments.

Metals
Treatment effectiveness will depend on the specific metal and its characteristics at the site. A combination of treatment processes (using a Management Train approach) is therefore generally more effective to deal with a spectrum of heavy metals. This will usually involve sedimentation processes (typically effective in removing particulates and associated particulate-bound pollutants down to approximately 10 μm if well designed) followed by filtration processes (eg bioretention) for finer particles. The removal of dissolved metals depends on the metal form and on the composition of the sorption or ion-exchange medium.

The BMP database does not include any data on hydrocarbon or PAH removal. However, work by Jefferies and Napier (2008) and Jefferies *et al* (2008) concluded that it is better to control oils and PAHs in soil-based SuDS at locations that are periodically wet and dry, such as in the base of detention basins, filter strips, swales, bioretention systems or infiltration basins. The pollutants, once removed from the runoff, will break down much more readily into harmless compounds in components where they are retained on the surface rather than under water in a pond or wetland.

Nutrient (normally represented by total nitrogen and phosphorous) removal can be important, particularly for nitrate- or phosphate-sensitive receiving water bodies and water bodies with high amenity value. Temporary saturated storage or slow conveyance zones, such as within bioretention systems (**Chapter 18)** or wetlands (**Chapter 23**) can reduce nutrient levels. Street sweeping has also been demonstrated to be an effective pollution prevention measure for nutrient control through removal of nutrient sources (**Chapter 27**).

The properties of pathogens such as E.coli and Enterrococci (usually present where there are misconnections from foul sewers or animal faeces) make their removal in natural treatment facilities difficult, although SuDS components do tend to reduce bacteria counts where they are associated with solids.

26.6.2 SuDS performance variability

The BMP database research outputs (WERF, 2014), the research undertaken by Jefferies (2004) and other research findings (including Ellis *et al*, 2012) all conclude that different components (with individual integral unit treatment processes) exhibit different capacities for removal of specific pollutants or pollutant groups.

However, the performance of any SuDS component is also inherently variable and pollutant removal effectiveness depends on a wide range of variables including (among others):

- the concentration of the inflow (eg efficiencies tend to be higher with higher inflow concentrations)
- the climate and time of year (eg temperature and vegetation growth can influence treatment processes)

- the condition of the component (eg recent maintenance activities and prior frequency of maintenance could influence removal rates)
- the design characteristics of the particular component (eg slopes, flow paths, retention times)
- the rainfall intensity and duration of any particular event (which will influence flow velocities, scour rates etc).

26.6.3 Groundwater protection

The conclusions of two studies into the extent to which surface water runoff may pose a risk to groundwater are presented in **Annex 4**. Overall conclusions can be summarised as follows:

- The overall risk to groundwater through porous media from the key contaminants associated with highway runoff is low.
- The presence of organic matter within the topsoil and underlying soils of surface-based infiltration systems, along with the opportunity for microbial mediated degradation of the PAH and TPH content of highway runoff through a sufficient depth of unsaturated zone, provides a significant degree of protection of underlying groundwater.
- The vast majority of heavy metals, PAHs and TPHs are retained in the top 10 cm of soil. An overlying vegetative layer will further reduce the risk of their movement to groundwater.
- Repeated delivery of contaminant mass over an extended period of time to an area (or volume) of unsaturated zone will eventually lead to the sorption properties of the material being exhausted. Ultimately, in the case of conservative pollutants such as metals, the soil column under the infiltration area will become saturated and breakthrough to groundwater will occur. The surface area and geometry of the infiltration system are therefore important for reducing risks, together with appropriate monitoring and maintenance programmes. Research presented in Scott Wilson (2010) suggests that, for typical highway loadings, cadmium (as an example) took between 54 and 714 years to move through 1 m of different types of unsaturated aquifer material. It is therefore considered unlikely that soil removal and component rehabilitation would be required during the design life of the system for lower hazard sites.
- Source control measures such as grass filter strips, swales and detention areas should be priority features of SuDS networks serving urbanised networks and highways, where oil contamination may be significant (Jefferies and Napier, 2008, and Jefferies *et al*, 2008).

26.7 METHODS FOR MANAGING POLLUTION RISKS

The risk posed by surface water runoff to the receiving environment is a function of:

- the pollution hazard at a particular site (ie the pollutant **source**)
- the effectiveness of SuDS treatment components in reducing levels of pollutants to environmentally acceptable levels, and/or the effectiveness of underlying soil layers in protecting the receiving groundwater (ie the pollutant **pathway**)
- the sensitivity of the receiving environment (ie the environmental **receptor**).

Land use is the primary influencing factor in the quality of urban surface water runoff (Royal Haskoning, 2010) and can therefore be used to represent the likely significance of the expected pollutant concentrations and loadings generated during rainfall events (ie the pollution hazard posed by the site).

Determining the hazard posed by the land use activities at a site and the extent to which underlying soil layers and/or proposed treatment components reduce the associated risk can be done using a variety of methods that vary in complexity and data requirements. The different generic methods can be summarised as:

- simple qualitative methods (using indices of likely pollution levels and SuDS performance capacities)
- established risk screening methods

- detailed risk assessment methods
- process-based treatment modelling methods (which, where used, are likely to form part of a detailed risk assessment).

Each of these methods is summarised in **Table 26.1** and described in more detail in the subsequent sections.

TABLE 26.1 Approaches to water quality risk management

Design method	Hazard characterisation	Risk reduction	
		For surface water	For groundwater
Simple index approach	Simple pollution hazard indices based on land use (eg **Table 26.2** or equivalent)	Simple SuDS hazard mitigation indices (eg **Table 26.3** or equivalent)	Simple SuDS hazard mitigation indices (eg **Table 26.4** or equivalent)
Risk screening[1]	Factors characterising traffic density and extent of infiltration likely to occur (eg **Table 26.5** or equivalent)	N/A	Factors characterising unsaturated soil depth and type, and predominant flow type through the soils (eg **Table 26.5** or equivalent)
Detailed risk assessment	Site specific information used to define likely pollutants and their significance	More detailed, component specific performance information used to demonstrate that the proposed SuDS components reduce the hazard to acceptable levels	
Process-based treatment modelling	Time series rainfall used with generic pollution characteristics to determine statistical distributions of likely concentrations and loadings in the runoff	Models that represent the treatment processes in the proposed SuDS components give estimates of reductions in event mean discharge concentrations and total annual load reductions delivered by the system	

Note

1 Risk assessment may be required as a result of the risk screening process.

Table 4.3 (**Chapter 4**) sets out which of these methods is required – for different generic land use types and receiving waters. Process-based modelling is not currently readily available for SuDS design in the UK, and is not therefore specified as a requirement. However, where robust models can be developed by designers, this approach should not be discounted as a future option for SuDS design.

It is important to ensure that risks to both surface and groundwater are managed effectively, and the approach taken should be agreed with the drainage approving body and/or environmental regulator in advance of the design, as local differences in requirements may exist.

Approaches that consider a number of key pollutant types are recommended because:

- receiving water quality standards tend to be specified in terms of individual pollutant thresholds (**Section 26.4**)
- different components tend to have different capacities to remove different types of pollutants (**Section 26.6**)
- any component (proprietary product or otherwise) will need to demonstrate performance across a range of pollutants, or where this is not possible, different types of component will be needed to remove different pollutants. A series of sediment removal components, such as gulley pots, would be unlikely to meet the performance requirements for the full suite of pollutants.

26.7.1 Simple index approach

The simple method described in this section, and summarised in **Box 26.2**, has been developed from that set out in Ellis *et al* (2012), a summary of which is presented in **Annex 5**.

The method is guided by the land use and SuDS performance evidence (**Section 26.6**). However, the variations in the approaches and data collected between studies, the wide ranges in pollution concentrations involved (pre and post treatment) and the paucity of UK data all mean that the evidence has had to be supplemented with theoretical understanding regarding the processes likely to deliver higher levels of removal of specific contaminants. The method has then been applied to a range of development scenarios to check that they deliver appropriate outputs.

If the indices are not considered to be appropriate – either for the land use or for the proposed mitigation, then the designer can either use alternative measures of hazard and risk mitigation, using a bespoke risk assessment process (**Section 26.7.3**), or justify alternative indices using similar evidence and/or process understanding to that discussed in this chapter and presented in **Annexes 1–5**.

BOX 26.2 **Steps of the simple index approach**

Step 1 – Allocate suitable pollution hazard indices for the proposed land use

Step 2 – Select SuDS with a total pollution mitigation index that equals or exceeds the pollution hazard index

Step 3 – Where the discharge is to protected[1] surface waters or groundwater, consider the need for a more precautionary approach

Note:

1 Designated as those protected for the supply of drinking water (**Table 4.3**).

Step 1 Define pollution hazard indices

Pollution hazard indices are presented in **Table 26.2** for the same range of land use categories used in **Table 4.3** (water quality standard 2, **Chapter 4**).

The indices range from 0 (no pollution hazard for this contaminant type) to 1 (high pollution hazard for this contaminant type).

Step 2 Determine SuDS pollution mitigation indices

To deliver adequate treatment, the selected SuDS components should have a total pollution mitigation index (for each contaminant type) that equals or exceeds the pollution hazard index (for each contaminant type):

Total SuDS mitigation index ≥ pollution hazard index
(for each contaminant type) (for each contaminant type)

Where the only destination of the runoff is to a surface water – that is there is no infiltration from the SuDS to groundwater – the surface water indices should be used, as suggested in **Table 26.3**.

In England and Wales, where the principal destination of the runoff is to a surface water, but small amounts of infiltration may occur from unlined components (Interception), then the groundwater indices should be used for the discharge to groundwater (as suggested in **Table 26.4**), and the surface water indices should be used for the main surface water discharge (as suggested in **Table 26.3**). In Scotland and Northern Ireland, groundwater risk management is not a requirement for this scenario.

Where the principal destination of the runoff is to groundwater, but discharges to surface waters may occur once the infiltration capacity is exceeded, the groundwater indices should be used, as suggested in **Table 26.4**. The risk to surface waters will be low, as dilution will be high for large events, so treatment is not required.

TABLE 26.2 Pollution hazard indices for different land use classifications

Land use	Pollution hazard level	Total suspended solids (TSS)	Metals	Hydro-carbons
Residential roofs	Very low	0.2	0.2	0.05
Other roofs (typically commercial/ industrial roofs)	Low	0.3	0.2 (up to 0.8 where there is potential for metals to leach from the roof)	0.05
Individual property driveways, residential car parks, low traffic roads (eg cul de sacs, homezones and general access roads) and non-residential car parking with infrequent change (eg schools, offices) ie < 300 traffic movements/day	Low	0.5	0.4	0.4
Commercial yard and delivery areas, non-residential car parking with frequent change (eg hospitals, retail), all roads except low traffic roads and trunk roads/motorways[1]	Medium	0.7	0.6	0.7
Sites with heavy pollution (eg haulage yards, lorry parks, highly frequented lorry approaches to industrial estates, waste sites), sites where chemicals and fuels (other than domestic fuel oil) are to be delivered, handled, stored, used or manufactured; industrial sites; trunk roads and motorways[1]	High	0.8[2]	0.8[2]	0.9[2]

Notes

1 Motorways and trunk roads should follow the guidance and risk assessment process set out in Highways Agency (2009).

2 These should only be used if considered appropriate as part of a detailed risk assessment – required for all these land use types (Table 4.3). When dealing with high hazard sites, the environmental regulator should first be consulted for pre-permitting advice. This will help determine the most appropriate approach to the development of a design solution.

Where a site land use falls outside the defined categories, the indices should be adapted (and agreed with the drainage approving body) or else the more detailed risk assessment method should be adopted.

Where nutrient or bacteria and pathogen removal is important for a particular receiving water, equivalent indices should be developed for these pollutants (if acceptable to the drainage approving body) or the risk assessment method adopted.

Where the mitigation index of an individual component is insufficient, two components (or more) in series will be required, where:

$$\textbf{Total SuDS mitigation index} = \textbf{mitigation index}_1 + 0.5\,(\textbf{mitigation index}_2)$$

Where:

mitigation Index_n = mitigation index for component n

A factor of 0.5 is used to account for the reduced performance of secondary or tertiary components associated with already reduced inflow concentrations.

TABLE 26.3 Indicative SuDS mitigation indices for discharges to surface waters

	Mitigation indices[1]		
Type of SuDS component	**TSS**	**Metals**	**Hydrocarbons**
Filter strip	0.4	0.4	0.5
Filter drain	0.4[2]	0.4	0.4
Swale	0.5	0.6	0.6
Bioretention system	0.8	0.8	0.8
Permeable pavement	0.7	0.6	0.7
Detention basin	0.5	0.5	0.6
Pond[4]	0.7[3]	0.7	0.5
Wetland	0.8[3]	0.8	0.8
Proprietary treatment systems[5,6]	These must demonstrate that they can address each of the contaminant types to acceptable levels for frequent events up to approximately the 1 in 1 year return period event, for inflow concentrations relevant to the contributing drainage area.		

Notes

1 SuDS components only deliver these indices if they follow design guidance with respect to hydraulics and treatment set out in the relevant technical component chapters.

2 Filter drains can remove coarse sediments, but their use for this purpose will have significant implications with respect to maintenance requirements, and this should be taken into account in the design and Maintenance Plan.

3 Ponds and wetlands can remove coarse sediments, but their use for this purpose will have significant implications with respect to the maintenance requirements and amenity value of the system. Sediment should normally be removed upstream, unless they are specifically designed to retain sediment in a separate part of the component, where it cannot easily migrate to the main body of water.

4 Where a wetland is not specifically designed to provide significantly enhanced treatment, it should be considered as having the same mitigation indices as a pond.

5 See **Chapter 14** for approaches to demonstrate product performance. A British Water/Environment Agency assessment code of practice is currently under development that will allow manufacturers to complete an agreed test protocol for systems intended to treat contaminated surface water runoff. Full details can be found at: **http://tinyurl.com/qf7yuj7**

6 SEPA only considers proprietary treatment systems as appropriate in exceptional circumstances where other types of SuDS component are not practicable. Proprietary treatment systems may also be considered appropriate for existing sites that are causing pollution where there is a requirement to retrofit treatment. SEPA (2014) also provides a flowchart with a summary of checks on suitability of a proprietary system.

TABLE 26.4 Indicative SuDS mitigation indices for discharges to groundwater

Characteristics of the material overlying the proposed infiltration surface, through which the runoff percolates[1]	TSS	Metals	Hydrocarbons
A layer of dense vegetation underlain by a soil with good contaminant attenuation potential[2] of at least 300 mm in depth[3]	0.6[4]	0.5	0.6
A soil with good contaminant attenuation potential[2] of at least 300 mm in depth[3]	0.4[4]	0.3	0.3
Infiltration trench (where a suitable depth of filtration material is included that provides treatment, ie graded gravel with sufficient smaller particles but not single size coarse aggregate such as 20 mm gravel) underlain by a soil with good contaminant attenuation potential[2] of at least 300 mm in depth[3]	0.4[4]	0.4	0.4
Constructed permeable pavement (where a suitable filtration layer is included that provides treatment, and including a geotextile at the base separating the foundation from the subgrade) underlain by a soil with good contaminant attenuation potential[2] of at least 300 mm in depth[3]	0.7	0.6	0.7
Bioretention underlain by a soil with good contaminant attenuation potential[2] of at least 300 mm in depth[3]	0.8[4]	0.8	0.8
Proprietary treatment systems[5, 6]	These must demonstrate that they can address each of the contaminant types to acceptable levels for inflow concentrations relevant to the contributing drainage area.		

Notes

1 All designs must include a minimum of 1 m unsaturated depth of aquifer material between the infiltration surface and the maximum likely groundwater level (as required in infiltration design – **Chapter 25**).

2 For example as recommended in Sniffer (2008a and 2008b), Scott Wilson (2010) or other appropriate guidance.

3 Alternative depths may be considered where it can be demonstrated that the combination of the proposed depth and soil characteristics will provide equivalent protection to the underlying groundwater – see note 1.

4 If significant volumes of sediment are allowed to enter an infiltration system, there will be a high risk of rapid clogging and subsequent system failure.

5 See **Chapter 14** for approaches to demonstrate product performance. Note: a British Water/Environment Agency assessment code of practice is currently under development that will allow manufacturers to complete an agreed test protocol for systems intended to treat contaminated surface water runoff. Full details can be found at: **www.britishwater.co.uk/Publications/codes-of-practise.aspx**

6 SEPA only considers proprietary treatment systems as appropriate in exceptional circumstances where other types of SuDS component are not practicable. Proprietary treatment systems may also be considered appropriate for existing sites that are causing pollution, where there is a requirement to retrofit treatment. WAT-RM-08 (SEPA, 2014) also provides a flowchart with a summary of checks on suitability of a proprietary system.

The following should be noted:

- Where the indices are not considered representative by the designer, a risk assessment can be undertaken (**Section 26.7.3**).
- Components should always be designed for treatment, as described in the design guidance set out in the individual component chapters. If they are undersized, incorrectly designed or constructed or inadequately maintained, their treatment performance could be significantly affected. Component checklists (**Appendix B**) can be used to confirm design and construction adequacy and set appropriate maintenance regimes.
- Where the infiltration component itself does not provide sufficient pollution mitigation, the design should include upstream SuDS components that are lined to prevent infiltration from occurring. The mitigation indices set out in **Table 26.3** (for discharges to surface water) should be used for any upstream treatment.

Step 3 Consider the need for a precautionary approach where discharges are to protected waters

In England and Wales, reference to local planning documents should also be made to identify any additional protection required for sites due to habitat conservation (**Chapter 7**). The implications of developments on, or in close proximity to, an area with an environmental designation, such as a site of special scientific interest (SSSI), should be considered via consultation with relevant conservation bodies such as Natural England.

In England and Wales, where the discharge is to protected surface waters or groundwater, an additional treatment component (ie over and above that required for standard discharges), or other equivalent protection, is required that provides environmental protection in the event of an unexpected pollution event or poor system performance. Protected surface waters are those designated for drinking water abstraction. In England and Wales, protected groundwater resources are defined as Source Protection Zone 1. In Northern Ireland, a more precautionary approach may be required, and this should be checked with the environmental regulator on a site-by-site basis.

26.7.2 Groundwater risk screening

A risk screening approach is required by the environmental regulators in England and Wales for medium hazard sites (**Table 4.3**). In Northern Ireland, the environmental regulator should be consulted to determine whether a risk screening approach is required.

The approach allows assessment of scenarios where the infiltration of water from surface runoff may require detailed risk assessment. The risk matrix used in HA (2009b), as updated by Scott Wilson (2010), provides a method for assessing the acceptability of Interception and infiltration SuDS components at a site. The matrix is based on the understanding that the risk posed by the runoff is a function of:

- the likely contamination hazard posed by the land use
- the amount of water likely to be infiltrated
- the attenuation potential of the soil or unsaturated zone for reducing the risk associated with pollutants present in highway runoff that may pose a risk to groundwater.

The matrix from HA (2009b) has been slightly modified here to make it more relevant for general SuDS applications and is presented in **Table 26.5**. The method requires each risk element (RE) (numbered 1–8 in column 1 and described in column 2) to be assigned a risk score (RS). The risk score will either be low (a score of 1), medium (a score of 2) or high (a score of 3) depending on the site characteristics described in columns 3–5 of the same table. For each risk element (RE), the risk score (RS) is then multiplied by the weighting factor (WF) given in column 6.

The risk scores for each risk element are then added together to give a total risk score for the SuDS component:

$$\text{Total risk score} = \sum_{RE=1}^{8} RS \times WF$$

Interpretation of the total outcome score is provided in **Table 26.6**, which guides the designer on the likely acceptability of different design solutions, and appropriate subsequent actions to take.

Where relevant data is not available to the designers, the likely worst-case characteristics should be assumed until suitable investigations have been undertaken.

TABLE 26.5 Risk matrix (from Highways Agency, 2009, after Scott Wilson, 2010)

Risk element (RE)		Risk score (RS)			Weighting factor (WF)
Element number	**Element description**	**Low risk (score 1)**	**Medium risk (score 2)**	**High risk (score 3)**	
1	Pollution hazard Traffic density	All standard urban land use types (excluding high hazard and trunk roads/motorways)			15
2	Standard Average Annual Rainfall depth	< 740 mm	740–1060 mm	> 1060 mm	15
3	Type of SuDS	Continuous unlined linear collection and conveyance components (eg filter strips, swales)	Shallow soakaway (eg infiltration basin/ trench, permeable pavement) draining < 5000 m2 runoff area		15
4	Unsaturated zone depth (ie depth of between infiltration surface and groundwater table)	> 15 m	5–15 m	1– 5 m	20
5	Predominant flow type through soils between infiltration surface and groundwater	Intergranular flow (occurs in unconsolidated or non-fractured consolidated deposits and fine or medium sands)	Mixed fracture and intergranular flow (occurs in fractured consolidated deposits and medium or coarse sands)	Fractured flow (occurs in heavily consolidated sedimentary deposits, igneous and metamorphic rocks and very coarse sands)	20
6	Unsaturated zone material: clay content	> 15% clay	1–15% clay	< 1% clay	5
7	Unsaturated zone organic carbon content: soil organic matter (SOM) content	> 15% SOM	1–15% SOM	< 1% SOM	5
8	Unsaturated zone material: soil pH	> 8	5–8	< 5	5

TABLE 26.6 **How to interpret the groundwater risk screening results**

Total risk score	Risks to groundwater	Interpretation
< 180	Low or medium	Use simple index approach Note: For discharges to protected groundwater bodies, implement an upstream treatment component that will provide groundwater protection in the event of an unexpected pollution event or poor system performance
180–250	High	Discharges may require an environmental licence or permit. Obtain pre-permitting advice first from the environmental regulator. Risk assessment likely to be required
> 250	Very high	Unacceptable

26.7.3 Detailed risk assessment

There are situations where a risk assessment method is either required (as defined in water quality standard 2, **Table 4.3**) or chosen by the designer and/or SuDS approving body as best meeting the needs for designing the appropriate treatment system for the site.

The scale of any risk assessment should be appropriate to the scale of the risk posed by the site: the significance of the potential pollution hazard combined with the sensitivity of the receiving water body. In the situations where the development proposal is heavily influenced by highway traffic in excess of 15,000 AADT, and is not associated with other pollutant sources, an assessment methodology as described in Annex I, Method C of HA (2009b). HA (2009b) or equivalent local authority guidance can be followed and may be required by the drainage approving body. Some guidance on risk assessment for surface water discharges to surface water bodies is set out (for England and Wales) in EA (2014) and (for Scotland) in SEPA (2014). Guidance on risk assessment for discharges of surface water to groundwater is set out (for England and Wales) in EA (2013), for Scotland in SEPA (2009) and for Northern Ireland in EHS (2001).

At the time of writing, the way in which Northern Ireland's groundwater protection policy is applied and integrated into SuDS policy development is under consideration, and the guidance in this manual should therefore be considered interim until Northern Ireland specific policy is available.

The risk assessment for each outfall or discharge point should:

a) determine and justify the range and likely significance and levels of pollutant(s) that may be washed off the site

b) state the baseline environmental quality, any environmental designations and relevant environmental standards (eg EQSs)

c) in the event of multiple surface water discharges from the same development, take account of any increased risk to the catchment from the cumulative impact of several outfalls

d) determine the scale of the potential risk to groundwater through taking account of the scale of the discharge, the depth of the discharge, the vulnerability of the groundwater body (eg soil and aquifer properties and seasonal variation in depth to water table)

e) determine and justify the effectiveness of the proposed drainage system and/or the unsaturated soil and aquifer layers in reducing the levels of pollutants to acceptable levels, taking account of the inherent uncertainty

f) summarise the residual risk to the receiving environment

g) use supporting data from site investigations

h) meet the requirements of the appropriate drainage approving body and/or environmental regulator.

The risk screening approach set out in **Section 26.7.2** may be used as an initial stage in any groundwater risk assessment. The evidence presented in Annex 4 may also be used where appropriate.

Where compound substances (eg oils) are considered a risk, it is good practice to take a risk indicator (such as benzene) and use that to determine potential impacts within any risk assessment. Benzene has both an EQS and a drinking water standard (DWS). There may also be specific British Standards of relevance eg BS EN 858-1:2002.

26.7.4 Process-based treatment modelling

One way of demonstrating the likely performance of a SuDS component or series of components in reducing pollutant loadings to the receiving water body is to use a long rainfall time series as input to a process-based surface or groundwater model that represents:

1. the pollutant build-up and wash-off processes and the resulting statistical distributions of the likely pollutant loadings entering the SuDS
2. the treatment processes provided by individual and combined SuDS units and/or the soil and aquifer layers between the infiltration surface and the groundwater
3. the impact of climate (including antecedent conditions, soil saturation levels, vegetation state etc).

In this way, a representative picture of the annual load discharged from the system and its variability can be developed and considered for compliance with receiving water body standards (these would need to be set by the local environmental regulator). Such approaches have been adopted in Australia and across the USA, but datasets to calibrate such models are currently sparse in the UK, and experience with their use is limited. However, in the interest of promoting research and scientific development in this area, this approach should not be precluded, and it is included here for completeness and to demonstrate its future potential.

Where designers wish to use a modelling approach, this should be agreed with the approving body and environmental regulator in advance of the design.

26.8 DESIGNING A TREATMENT SYSTEM USING A SUDS MANAGEMENT TRAIN

A number of SuDS components in series (a Management Train) through a development site facilitates the capture, conveyance and storage of surface water runoff while delivering Interception and pollution risk management. The range of SuDS components available provides flexibility to designers to integrate surface water management with urban design and to meet water quantity, amenity and biodiversity design criteria in a range of different ways.

A SuDS Management Train is a robust pollutant removal strategy. Using a number of different SuDS components in series will help target a good range of particulate-bound and dissolved pollutants, will deliver gradual improvement in water quality and will act as a buffer for accidental spills and intermittent high pollutant loads. The suitability of different SuDS components within the Management Train is indicated in **Table 26.7**. A single SuDS component (eg a bioretention system) which has a high capacity for the removal of pollutants, may be suitable in some scenarios – provided its functionality is protected from sediment build-up and it can deliver the required hydraulic criteria for the contributing catchment.

The Management Train can be adapted or extended to deliver appropriate levels of risk management, depending on the land use and sensitivity of the receiving water body (**Table 4.3**). Where there are several different land use surfaces on a site, the design should take account of the fact that some areas will potentially need more treatment than others. Where ownership of the site is split (eg a number of industrial units), the design should ensure that adequate treatment is delivered on each plot, so that responsibility for any pollution and associated remedial maintenance from the plot can reside with the plot owner. Pollution prevention strategies may also form part of the risk management approach for industrial sites.

TABLE 26.7 Indicative suitability of SuDS components within the Management Train

SuDS component	Interception[1]	Close to source/ primary treatment	Secondary treatment	Tertiary treatment
Rainwater harvesting	Y			
Filter strip	Y	Y		
Swale	Y	Y	Y	
Filter drain	Y		Y	
Permeable pavement	Y	Y		
Bioretention	Y	Y	Y	
Green roof	Y	Y		
Detention basin	Y	Y	Y	
Pond	[3]	Y[2]	Y	Y
Wetland	[3]	Y[2]	Y	Y
Infiltration system (soakaways/ trenches/ blankets/basins)	Y	Y	Y	Y
Attenuation storage tanks	Y[4]			
Catchpits and gullies		Y		
Proprietary treatment systems		Y[5]	Y[5]	Y[5]

Notes

1 Interception components are also normally also a treatment component (excluding rainwater harvesting which only removes runoff from the system)

2 for roof runoff only

3 Interception design may be possible in certain scenarios, but would require detailed justification

4 if unlined and design performance can be demonstrated (noting the need to protect groundwater)

5 where design performance can be demonstrated

The following guidance should be followed in the development of a robust treatment design for the site:

1 **Each component should be designed and constructed to meet the design requirements set out in the individual technical component chapters (Chapters 11–23).**

In common with any operational system, long-term maintenance is required in order to maintain their future treatment functionality.

2 **Sediment should be removed as far upstream in the drainage system as possible.**

Sediment control components that are located close to the runoff surface allow sediment build-up to occur gradually in dry features and at shallow depths, facilitating the breakdown and degradation of the organic particulates and straightforward and cost-effective sediment removal. Sediment trapping provides important removal of a range of contaminants that are adsorbed onto sediment surfaces and upstream sediment controls protect downstream components from damage or poor performance due to sediment build-up either on the surface or within subsurface media or soils. This is particularly important for infiltration systems.

3 **Pollution control and treatment should be implemented at a plot level for individually owned or operated plots, with open downstream conveyance systems where practicable, so that any residual contamination is obvious and can be sourced.**

Pollution risks should be made the responsibility of the site owner/operator.

Access roads and transportation routes to and from industrial premises where tanker or other spillage accidents are a pollution risk, should be treated at source where possible to allow easy identification, access, clean-up and remediation, ideally using open (preferably vegetated) conveyance systems.

4 **Downstream ponds or wetlands (or other components with permanent water) should be considered with respect to their delivery of the following three key benefits:**

- a body of water able to help dilute a major pollution accident and provide a quiescent zone (ie normally non-moving) that allows oil separation and retention
- a "polishing" treatment component with a long retention time that uses filtration and settling techniques to remove finer sediments and dissolved pollutants from the runoff; this can help pollutant concentrations to reach acceptable environmental quality standards
- a suitably clean body of water that can provide an amenity and biodiversity value for the site.

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Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive, WFD)

ANNEX 1

Contaminants in urban runoff and their potential toxicity

There are few monitoring studies of direct urban runoff in the UK. However, there is a UK database of water quality data from water bodies in small urban catchments (Mitchell, 2005); a few UK studies of SuDS performance where urban runoff data has been monitored as the inflow (eg Woods Ballard *et al,* 2005, Royal Haskoning, 2012, Jefferies, 2004); the International BMP stormwater database (WERF, 2014), which has collated data from over 530 studies primarily across the US; and urban runoff data held within guidance documents such as DEP (2006) and OMOE (2003).

The Mitchell (2005) dataset is based on UK data, supplemented with northern European data to make the results more statistically robust. Measured pollutant concentrations in surface water runoff for different land uses for total suspended solids, cadmium, copper, zinc and nickel are presented in **Tables 26.8 to 26.12**. These pollutants have been selected as they are known to be prevalent in surface water runoff at levels that may be toxic in either acute or chronic exposure scenarios (and because the data is available).

In order to provide a comparison, summary data from the USA stormwater BMP database (Leisenring *et al,* 2014) is also provided. The BMP database provides data from studies looking at different types of SuDS components (rather than different land uses). Therefore, only the average concentrations across all studies are presented here.

WRc (2008) also presents data of suggested average surface water runoff concentrations from trunk roads and motorways. This data is likely to contain higher pollutant concentrations than required to be managed by SuDS in general development scenarios.

The tables then go on to compare concentrations of pollutants measured in surface water runoff with relevant environmental standards in an attempt to determine their likely significance (EA, 2014). Although there is significant variability in the data presented, they show the degree to which surface water runoff from development is polluted and the need for this to be addressed in order to meet environmental standards.

EA (2014) guidance on assessment of hazardous pollutants within surface water discharges provides some direction on appropriate methods to determine the acceptability of pollutants discharged in surface water runoff. Although the principal methods described in the document are applicable to continuous discharges and variable process discharges, the guidance suggests that for rainfall dependent discharges and non-continuous discharges (pertinent to SuDS), it is appropriate to compare likely runoff concentrations to environmental standards of receiving water bodies.

TABLE 26.8 Total suspended solids: summary of a selection of monitoring datasets

			Total suspended solids concentration		
	Reference	**Land use**	**25%ile (mg/l)**	**Mean (mg/l)**	**75%ile (mg/l)**
Observed runoff data	Mitchell (2005)	Urban open	57	126.3	279.8
		Industrial/commercial	18.1	50.4	140.4
		Residential	37.6	85.1	192.5
		Main highway	62.2	156.9	396.3
		Multi-lane highway	110.1	194.5	343.5
	US BMP database (Leisenring *et al*, 2014)	Average across all studies	19.8	48.7	113.7
	WRc (2008)	Trunk roads and motorways		244	
Environmental standards	Minimum concentration causing observable biological effects[1,2]		25		
	Mean level in minimally impaired ponds[2]		19		

Notes

1 Alabaster and Lloyd (1980)

2 Woods Ballard *et al* (2005)

ANNEX 1

TABLE 26.9 **Total cadmium: summary of a selection of monitoring datasets**

			Total cadmium concentration		
	Reference	**Land use**	**25%ile (µg/l)**	**Mean (µg/l)**	**75%ile (µg/l)**
Observed runoff data	Mitchell (2005)	All	1.3	2.2	3.7
	US BMP database (Leisenring *et al*, 2014)	Average across all studies	0.2	0.3	0.6
	WRc (2008)	Trunk roads and motorways		0.63	
Environmental standards	Surface water standard: minimum concentration causing observable biological effects[1]	0.66			
	Surface water standard: environmental quality standard for dissolved cadmium[2,3]	AA (annual average) ≤0.08 (< 40 mg/l $CaCO_3$) 0.08 (40–50 mg/l $CaCO_3$) 0.09 (50–100 mg/l $CaCO_3$) 0.15 (100–200 mg/l $CaCO_3$) 0.25 (> 200 mg/l $CaCO_3$)		MAC (maximum allowable concentration) ≤0.45 (< 40 mg/l $CaCO_3$) 0.45 (40–50 mg/l $CaCO_3$) 0.6 (50–100 mg/l $CaCO_3$) 0.9 (100–200 mg/l $CaCO_3$) 1.5 (> 200 mg/l $CaCO_3$)	
	Groundwater standard: minimum reporting values[4]	0.1			

Notes

1 Woods Ballard *et al* (2005)

2 Set by Directive 2008/105/EC (EQSD) and/or Annex 8 of Directive 2000/60/EC (WFD)

3 EA (2014) confirms validity of comparing total metal observations against dissolved metal EQSs

4 EA (2011)

TABLE 26.10 Total copper: summary of a selection of monitoring datasets

			Total copper concentration		
	Dataset	**Land use**	**25%ile (µg/l)**	**Mean (µg/l)**	**75%ile (µg/l)**
Observed runoff data	Mitchell (2005)	Urban open	19.8	27.9	39.2
		Developed open	22.3	51.1	117.1
		All highways	43.2	80.3	149.5
	US BMP database (Leisenring *et al*, 2014)	Average across all studies	5.6	10.9	22.0
	WRc (2008)	Trunk roads and motorways		91.22	
Environmental standards	Surface water standard for dissolved copper: environmental quality standard[1,2]	1 (0–50 mg/l $CaCO_3$) 6 (50–100 mg/l $CaCO_3$) 10 (100–250 mg/l $CaCO_3$) 28 (> 250 mg/l $CaCO_3$)			
	Surface water standard: minimum concentration causing observable biological effects[3]	5			
	Surface water standard: mean level in minimally impaired ponds[3]	12			
	Groundwater standard: 0.75 × MAC for drinking water standard[4]	1.5			

Notes

1 Set by Directive 2008/105/EC (EQSD) and/or Annex 8 of Directive 2000/60/EC (WFD); more recent updates specify concentrations in terms of bioavailability (Defra, 2014)

2 EA (2014) confirms validity of comparing total metal observations against dissolved metal EQSs

3 Woods Ballard *et al* (2005)

4 Scottish Government (2014)

ANNEX 1

TABLE 26.11 Total zinc: summary of a selection of monitoring datasets

			Total zinc concentration		
	Dataset	**Land use**	**25%ile (µg/l)**	**Mean (µg/l)**	**75%ile (µg/l)**
Observed runoff data	Mitchell (2005)	Urban open	102	203	403.9
		Industrial/commercial	84.7	188.6	420.2
		Residential	192.8	296.9	457.2
		Main highway	97.7	253.1	655.5
		Multi-lane highway	284	417.3	613.3
	US BMP database (Leisenring *et al*, 2014)	Average across all studies	28.7	55.9	111.6
	WRc (2008)	Trunk roads and motorways		352.6	
Environmental standards	Surface water standard for dissolved zinc: environmental quality standard[1,2]	8 (0–50 mg/l $CaCO_3$) 50 (50–100 mg/l $CaCO_3$) 75 (100–250 mg/l $CaCO_3$) 125 (> 250 mg/l $CaCO_3$)			
	Surface water standard: minimum concentration causing observable biological effects[3]	30			
	Surface water standard: mean level in minimally impaired ponds[3]	97			
	Groundwater standard: EPA[4]	5			

Notes

1 Set by Directive 2008/105/EC (EQSD) and/or Annex 8 of Directive 2000/60/EC (WFD); more recent updates specify concentrations in terms of bioavailability (Defra, 2014)

2 EA (2014) confirms validity of comparing total metal observations against dissolved metal EQSs

3 Woods Ballard *et al* (2005)

4 US EPA (2013)

TABLE 26.12 Total nickel: summary of a selection of monitoring datasets

	Dataset	Land use	Total nickel concentration		
			25%ile (µg/l)	Mean (µg/l)	75%ile (µg/l)
Observed runoff data	Mitchell (2005)	Urban open	10.2	14.8	21.6
		Developed open	18.2	30.4	50.6
	US BMP database (Leisenring *et al*, 2014)	Average across all studies	2.8	4.6	7.9
Environmental standards	Surface water standard for dissolved nickel: environmental quality standard[1,2]	20			
	Surface water standard: minimum concentration causing observable biological effects[3]	5			
	Groundwater standard. 0.75 × MAC for drinking water standard[4]	15			

Notes

1 Set by Directive 2008/105/EC (EQSD) and/or Annex 8 of Directive 2000/60/EC (WFD); also specified in Scottish Government (2014)
2 EA (2014) confirms validity of comparing total metal observations against dissolved metal EQSs
3 Woods Ballard *et al* (2005)
4 DWI (2010)

Oil and grease levels measured in urban catchments in the UK are 2–5 mg/l for residential areas, 5–25 mg/l for general urban areas (including commercial and industrial sites) and of the order of 200 mg/l for main roads (Mitchell, 2005). There are no specified EQSs for these substances, but their presence is usually visible and unsightly, so maximum removal is appropriate. Polycyclic aromatic hydrocarbons (PAHs) have specified EQSs, but their concentrations in surface water runoff have not been monitored in the datasets referred to above. Average event mean concentrations (EMCs) of fluoranthene are given by WRc (2008) for trunk roads as 1.02 µg/l compared to a maximum allowable concentration EQS of 0.12 µg/l.

▶ **Event mean concentration (EMC)** – A method for characterising pollutant concentrations in a receiving water from a runoff event, often chosen for its practicality. The value is determined by compositing (in proportion to flow rate) a set of samples, taken at various points in time during a runoff event, into a single sample for analysis.

Total nitrogen levels measured in urban catchments in the UK were at a level of the order of approximately 5 mg/l for the majority of urban areas, although at only around 1 mg/l for main roads (Mitchell, 2005).

ANNEX 2

Types of pollutant removal mechanisms in SuDS

Sedimentation
Sedimentation is one of the primary removal mechanisms in SuDS. Most pollution in runoff is attached to sediment particles, and so removal of sediment results in a significant reduction in pollutant loads. Sedimentation is achieved by reducing flow velocities to a level at which the sediment particles fall out of suspension (finer particles requiring lower velocities) or by encouraging flocculation (which increases particle size). Very fine particles may remain in suspension and essentially be characterised as dissolved. Sediment requires periodic removal to permit the effective functioning of SuDS components. Care also has to be taken in design to minimise the risk of resuspension when extreme rainfall events occur.
Filtration and biofiltration
Pollutants that are conveyed in association with sediment may be filtered from runoff. This may occur through trapping within the soil or aggregate matrix, on plants or on geotextile layers within the construction. The location of any filtration will depend on the internal structure of the particular SuDS component. There will generally be a need to balance removal efficiency with the potential risk of blockage of the filtration component (and associated maintenance needs of the component, eg filter removal and replacement) although planting can often be used to help minimise blockage risks and lead to systems that are relatively self-maintaining.
Separation
Many hydrocarbons and some other pollutants (eg pollens) float on the surface of water as a immiscible "skin". Such pollutants can be skimmed off using separation processes, or can be trapped by vegetation, allowing subsequent degradation, for example by volatilisation and photolysis.
Adsorption
Adsorption occurs when pollutants attach or bind to the surface of sediment, soil, sand, aggregate or artificial material. The actual process is complex, but tends to be a combination of surface reactions. Change in acidity of runoff can either increase (higher pH) or decrease (lower pH) the adsorption of pollutants. Similarly, the winter use of de-icing salts can encourage the release of metals from the surface. Eventually, the materials onto which pollutants adsorb will become saturated and so this method of treatment will cease to be effective unless mechanisms for regeneration are available.
Biodegradation
In addition to the physical and chemical processes that may occur on and within a SuDS component, biological treatment may also occur. Microbial communities are likely to be established within the soil or aggregate matrix, using the oxygen within the free-draining materials and the nutrients supplied with the inflows, to degrade organic pollutants such as oils and grease. The level of activity of such bioremediation will be affected by the environmental conditions such as temperature and the supply of oxygen and nutrients. It also depends on the physical conditions, such as the suitability of the materials for colonisation. Ammonia and ammonium ions can be oxidised by bacteria in the ground to form nitrate, which is a highly soluble form of nitrogen. Nitrate is readily used as a nutrient by plants. In oxygen-limiting conditions, anaerobic bacteria can facilitate denitrification, in which the participation of several species of bacteria can eventually result in the complete reduction of nitrate to molecular nitrogen. This is an important process where excessive nitrate production threatens groundwater quality or eutrophication in surface waters.

Volatilisation
Volatilisation involves the transfer of a compound from the solid or solution phase to the atmosphere. The conversion to a gas or vapour is influenced by temperature, reducing pressure, chemical reaction or a combination of these processes. The rate of volatilisation of a compound is dependent on its vapour pressure, as well as the characteristics of the surrounding soil. In SuDS systems, volatilisation is primarily concerned with organic compounds associated with petroleum products and pesticides.
Precipitation
This process is the most common mechanism for removing soluble metals. Precipitation involves chemical reactions between pollutants and compounds in the soil or aggregate matrix that transform dissolved constituents into particles of insoluble precipitates. Metals are precipitated as hydroxides, sulphides and carbonates, depending on which precipitants are present and the pH level. Precipitation can remove most metals (eg arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, zinc) and many anionic species (eg phosphates, sulphates, fluorides), although to different levels according to the applied conditions.
Uptake by plants
In ponds and wetlands, uptake by plants (specifically via the biofilm growth around the plant structure) is an important removal mechanism for nutrients (phosphorous and nitrogen). Metals can also be removed in this manner, although intermittent maintenance may be required to remove the plants, otherwise there is the possibility that metals will be returned to the water when the plants die (Chapter 32 *Operation and maintenance*). Die-back can also be accompanied by a release of nutrients. Plants also create suitable conditions for deposition of metals, such as sulphides, in the root zone and also provide a microbiological environment that supports the biodegradation of organic pollutants.
Photolysis
The breakdown of surface-held organic pollutants by exposure to ultraviolet light.
Hydrolysis
The chemical breakdown of a compound due to reaction with water.
Oxidation
The combination of a compound with oxygen.
Reduction
The loss of oxygen from a compound.
Substitution
The replacement of one functional group in a compound with another.

ANNEX 3

SuDS performance data

Table 26.13 summarises an analysis of the data included within the International Stormwater BMP database (WERF, 2014), demonstrating the capability of a selection of different SuDS components in reducing pollution loadings in runoff. The water quality standards are drawn from those presented in the tables in **Annex 1**. This data indicates the performance of SuDS components in reducing the concentrations of pollutants within surface water runoff to or close to acceptable levels.

TABLE 26.13 Performance of SuDS components in reducing urban runoff contamination

		Concentration ranges: 25%ile – 75%ile				
		TSS (mg/l)	Total cadmium (µg/l)	Total copper (µg/l)	Total zinc (µg/l)	Total nickel (µg/l)
Inflow from urban surface (average values)[1]		20–114	0.2–0.6	6–22	29–112	3–8
Selected environmental standards (**Tables 26.1 to 26.5**):						
Surface water[5]		25	0.6[6]	6[6]	50[6]	20[6]
Groundwater[5]			0.1	1.5	5	15
Outflows from SuDS components:						
Vegetated/ surface SuDS components[1]	Filter strips	10–35	0.1–0.3	5–12	11–53	2–4
	Bioretention	5–20	0.04–0.1	4–10	5–29	3–8
	Swales	10–43	0.2–0.3	4–15	18–55	2–5
	Detention basins	10–47	0.1–0.4	2–12	6–58	2–4
	Retention ponds	4–28	0.1–0.4	3–7	11–39	2–6
	Wetland basins	4–21	0.1–0.4	2–6	11–33	
	Permeable pavements	14–44	0.3–0.5	4–11	2–29	1–3
Manufactured treatment components[2]	Biological filtration	2–5		N/A[4]	38–221	
	Filtration	7–26		3–10	19–59	
	Hydrodynamic or vortex separators[3]	10–71		6–17	34–107	
	Oil separators	16–87		6–18	60–121	
	Multi-process	2–8		3–16	9–27	

Notes

1 Leisenring *et al* (2014).

2 The above figures for manufactured products are based on a summary of 61 different proprietary systems (Leisenring *et al*, 2012) that passed the stormwater BMP database proprietary device policy. These figures are intended to be indicative of the likely performance of a particular category of proprietary devices. It is recommended that evidence is obtained to support any performance claims of an individual device as outlined in **Chapter 14, Section 14.5**.

3 Referred to as "manufactured device – physical" in WERF (2014).

4 N/A – not available, or fewer than three studies for system.

5 For relevant sources, see Annex 1 **Tables 26.8 to 26.12**.

6 Standard is for the dissolved metal, at 50–100 mg/l $CaCo_3$ concentration.

ANNEX 4

Groundwater protection evidence

Two recent studies in the UK have examined the potential risks posed to groundwater from runoff from trafficked areas.

Scott Wilson (2010) had the following objectives:

1 to quantify the extent to which contaminants in highway runoff may be leached, degraded or immobilised in the unsaturated zone and within the soakaway systems

2 to review and/or refine the boundary conditions defined for each risk category within HA (2009a) risk assessment method

3 to develop an improved groundwater risk methodology for predicting the risk to groundwater from highway runoff.

This research found the following:

- The time taken for contaminants to break through 1 m of different unsaturated aquifer materials varied. For cadmium (likely to be most rapidly conveyed, break through times ranged from 54 years (for oolitic limestone aquifer material) to 714 years for oolitic soils.
- Residual concentrations of fluoranthene and pyrene were reduced to below the limit of analytical detection within approximately 0.5 m depth of the unsaturated zone (using assumed biodegradation rates).
- The soil organic matter is extremely important in retaining and attenuating contaminant migration.
- The total mass of contaminant is more relevant than the concentration of that contaminant.
- The total volume of infiltrating water will be the significant influence on downward flux of the contaminant through the soil profile.

The overall conclusions of the research are as follows:

- The overall risk to groundwater through porous media from the key contaminants associated with highway runoff is low and the opportunity for microbial mediated degradation of the PAH and TPH content through a sufficient depth of unsaturated zone confers a significant degree of protection to underlying groundwaters.
- Organic soil layers will form an important additional barrier to the movement and attenuation of contamination.

The findings support the view that risks posed by lateral drainage collection components such as swales will be smaller than for point source infiltration components, and that Interception components, where infiltration rates are low, will pose a lower risk to groundwater.

The Sniffer project (Jefferies *et al*, 2008) had the following objectives:

1 to determine the risk of movement of pollutants through soil into groundwater in soft-engineered SuDS

2 to measure the immobilisation and degradation of priority pollutants and fate of nutrients in soft engineering SuDS

3 to identify the degradation products in a range of SuDS components

4 to determine the conditions for the optimal breakdown of oil and PAHs in the range of SuDS investigated.

The project conclusions are very similar to those stated in Scott Wilson (2010) and include the following:

1. The risks to groundwater from passing highway drainage onto soil based SuDS is low. There is evidence of only very low rates of downward movement of contaminants.
2. The vast majority of heavy metals, PAHs and TPHs are retained in the top 10 cm of soil. An overlying vegetative layer would take up some of the pollutants retained in the soil, further reducing the risk of their movement to groundwater.

ANNEX 5

Ellis *et al*, 2012

Middlesex University has undertaken work on the development of a water quality impact assessment methodology that can be applied to the assessment of SuDS (Ellis *et al*, 2012) and a summary of the approach proposed in that paper is described below. It should be noted that this method is not suitable for use in designing treatment systems for discharges to groundwaters (ie infiltration systems).

Step 1. Pollution index (PI) assessment

The individual pollutant indexing (**Table 26.13**) has been developed from consideration of the interquartile range of event mean concentration (EMC) data derived from 71 separate UK studies and referenced against regulatory EU environmental quality standards. The pollution index is then based on a scaling of the reported EMC distribution for the given pollutant group and the likelihood that the 50%ile EMC values will exceed receiving water body EQSs, specified either as maximum allowable concentration or annual average values.

Step 2. SuDS pollution mitigation index (PMI) assessment

The authors then adopt scaling ranges to indicate the removal potential by which different types of SuDS are able to remove different pollutant groups. The ranges adopted are between 0 and 1, and hence are only qualitative, that is a lower index value indicates a better treatment performance, but the allocated scores cannot be used to indicate the magnitude of the difference (**Table 26.14**).

Step 3. Land use pollution index (*LUPI*) and site pollution index (SPI) assessment

A land use pollution index (*LUPI*) (for each pollutant group) for the different land use areas contributing to the discharge point is evaluated by multiplying the pollution index (*PI*) by the pollution mitigation indices (*PMI*) for each SuDS component used.

$$Area\ LUPI_{TSS} = PI_{TSS} \times PMI_{TSS}SUDS_1 \times PMI_{TSS}SUDS_2 \times \ldots n$$

The final site pollution index (SPI) is an aggregation of the different LUPIs weighted by their area.

Step 4. Assessment against an environmental baseline

The final step is to make a comparison of the resulting averaged SPI index against a recognised value or standard for receiving water quality, in order to evaluate any likely risk exposure associated with the site SuDS discharge. The procedure then associates different SPI levels with different receiving water quality levels, for example the EA River Ecosystem Class (REC).

- REC standards have now been superseded by WFD standards; the relevant environmental regulator should be contacted to agree appropriate environmental standards.

The research sets out a structured impact assessment methodology, but has some limitations that potentially make it unsuitable for use as a generic SuDS design approach:

1. It does not include the determination of treatment requirements upstream of infiltration components (ie it accounts for the removal of pollutants from the discharge from the site to surface water bodies, but it does not take into consideration the potential need for treatment of the infiltrated water before discharge to groundwaters). This means that there is a risk of the method being misused by implying that the use of infiltration components can protect receiving surface water bodies, without considering the risk to groundwater.

2 The multiplicative procedure used considers the behaviour of each SuDS on a standalone basis rather than as a component in a Management Train. In reality, the removal performance of downstream SuDS components tends to be lower due to lower pollutant exposures and capabilities.

3 The method requires a determination regarding the acceptability of the impact level for different receiving water bodies. If an SPI of < 0.1 is considered appropriate for surface water discharges (ie negligible impact level), then a very high number of components would usually be required. If SPI of < 0.2 is considered acceptable (ie minimal impact level, small reduction in pollution tolerant tax), then this will still tend to require a higher number of components than general good practice might normally suggest.

However, the work provides a potential methodology that could be used in the design of treatment systems and is also a good basis for future studies and assessment. Where it is used, the full paper should be referenced, rather than relying on the information provided here.

ANNEX 5

TABLE 26.14 Impermeability and pollution indices for different land use types[1]

Land use surface type (LUST)	Impermeability (IMP_{RF})	Total suspended soluds pollution index (PI_{TSS})	Organic pollution index (PI_{Org})	Hydrocarbon pollution index (PI_{PAH})	Metals pollution index (PI_{HM})
Roofs					
▪ industrial/commercial	1.0	0.3	0.3–0.4	0.2	0.4–0.8
▪ residential	0.9	0.4–0.5	0.6–0.7	0.1	0.2–0.5
Highways					
▪ motorways	0.8–0.9	0.9	0.7	0.9	0.8
▪ major arterial highways	0.7–0.8	0.8	0.7	0.8	0.8
▪ urban distributor roads	0.6–0.7	0.7–0.8	0.5	0.8	0.7
▪ residential streets	0.4–0.6	0.4	0.6	0.6	0.6
▪ pavements	0.5–0.6	0.4	0.6	0.3	0.3
Car parks/hardstanding					
▪ industrial/commercial	0.6–0.8	0.6–0.7	0.6–0.7	0.7	0.4–0.5
▪ driveways (residential)	0.5	0.5	0.6	0.4	0.3
Open areas					
▪ gardens (all types)	0.1	0.3	0.2–0.3	0	0.01
▪ parks/golf courses	0.2	0.2–0.3	0.2	0	0.02
▪ grassed areas (including verges, all types)	0.1	0.2–0.3	0.2–0.3	0.05	0.05

Note

1 Pollution index values are based on reported land use type EMC distributions and impact potential thresholds from House *et al* (1993), Luker and Montague (1994), Butler and Clark (1995), D'Arcy *et al* (2000), Mitchell (2005) and Moy *et al* (2003).

TABLE 26.15 Pollution mitigation indices for different SuDS components and conventional pipe drainage

SuDS type	Total suspended solids pollution mitigation index (PMI_{TSS})	Hydrocarbon pollution mitigation index (PMI_{PAH})	Organic pollution mitigation index (PMI_{Org})	Heavy metal pollution mitigation index (PMI_{HM})
Filter drains	0.6	0.8	0.7	0.7
Porous asphalt	0.7	0.9	0.9	0.9
Porous paving	0.2	0.3	0.2	0.3
Sedimentation tank	0.95	0.95	0.95	0.95
Green roof	0.8–0.9	0.9	0.5	0.7–0.9
Filter strip	0.9	0.8	0.8	0.7
Swales	0.7	0.6	0.4	0.4
Soakaways	0.3	0.6	0.5	0.5
Infiltration trench	0.3	0.6	0.5	0.5
Infiltration basin	0.05	0.05	0.01	0.05
Retention pond	0.6	0.5	0.6	0.5
Detention basin	0.7	0.7	0.8	0.6
Extended detention basins	0.4	0.4	0.4	0.4
Lagoons	0.9	0.9	0.9	0.8
Contructed wetlands ▪ subsurface flow ▪ surface flow	 0.2 0.4	 0.1 0.2	 0.1 0.2	 0.1 0.2
Conventional gully and pipe drainage	1.0	1.0	1.0	1.0

27 POLLUTION PREVENTION STRATEGIES

Contents

Chapter 27

Pollution prevention strategies

This chapter discusses strategies that can be used to avoid or minimise the generation of pollutants and how to prevent pollutants mixing with runoff before it enters the drainage system.

Capturing, treating and removal of pollutants within the drainage system is the purpose of treatment design and is not discussed here. The mobilisation of pollutants from contaminated land is also not covered here.

- ▶ *Guidance on water quality management and treatment design is provided in Chapters 4 and 26 respectively, as well as the individual SuDS component chapters (Chapters 11–23).*
- ▶ *Chapter 31 provides details of temporary erosion and sediment control measures required to prevent pollutants from leaving sites during construction. It also provides guidance to help ensure site surface water management systems are appropriately implemented during construction projects.*
- ▶ *Managing the risk of mobilising pollutants from contaminated land is covered in Chapter 8.*

27.1 GENERAL DESCRIPTION

Pollution prevention strategies are methods used on site to manage pollutants at their source. These strategies may be part of:

- the approved site design or operational strategy, required in order to reduce environmental risks to acceptable levels
- standard operational best practice of the site users and/or operators
- community strategies promoted by local environmental bodies to raise awareness of the risks posed by pollutants in surface runoff and actions that can be taken to minimise them.

Many of these are common sense working practices and are relatively inexpensive and easy to implement. For example, dust and debris can be swept or vacuumed from a work area and disposed of as waste, instead of using a hose to wash it into a surface water drain or SuDS.

SuDS components capture and remove pollutants after they have mixed with rainfall, but they cannot remove 100% of the pollutants (**Chapter 4**). The most effective way of preventing pollution getting into surface water discharges is to prevent pollutants from entering the surface water drainage system in the first place. With new substances coming onto the market all the time that have the potential to be harmful to the natural environment, pollution prevention is becoming increasingly important. In some cases, pollution prevention strategies can be sufficient to remove the pollution risk downstream almost entirely.

For a high hazard site, pollution prevention may be a regulatory requirement, to ensure that the downstream drainage system does not pose an unacceptable risk to the receiving environment. Many pollution prevention strategies can reduce the maintenance requirements of downstream drainage components or prevent the need for clean-up and rehabilitation works, and may be promoted by drainage system owners/operators and/or local environmental groups.

Pollution prevention should follow a hierarchical approach:

1 **Avoid** the use of materials and activities that generate pollutants.
2 **Minimise** the use of materials and activities that generate pollutants.
3 **Prevent** pollutants mixing with rainfall.
4 **Capture** pollution within the drainage system for removal, treatment or clean-up and rehabilitation (where required).

Pollution prevention strategies, as discussed here, cover actions 1–3.

Pollution prevention strategies are most effective when they are an integral part of community behaviour and site management processes. This chapter provides information to help:

a) individuals, businesses and local authorities identify strategies for controlling pollutants at source and preventing contamination of surface water runoff
b) designers identify physical measures for preventing the mixing of pollutants with rainfall, or trapping pollutants before they enter SuDS.

The design of pollution prevention strategies needs to take into account the use of the site, the types of pollutants that may be present and the operational processes on the site. Different types of pollutants (as presented in **Table 4.1, Chapter 4**) may require different strategies.

The rest of this chapter summarises pollution prevention strategies, following the hierarchical approach set out above (**Sections 27.2–27.4**) and the education and training strategies required to facilitate their delivery (**Section 27.5**).

27.2 AVOID POLLUTING MATERIALS AND ACTIVITIES

Where possible, activities or materials that have the potential to result in pollution should be avoided or substituted.

An example of the effective removal of a pollutant source is the identification and removal of illicit connections of foul water discharges to SuDS. Surface SuDS will help in exposing the location and likely source of any wrongly connected inputs as poor water quality and possibly sewage solids/fungus may be visible. This can help identification of the problem by local homeowners, property owners or maintenance bodies and allow action to be taken. During the lifetime of the SuDS, further wrong connections may occur upstream, which may be identified by SuDS inspection regimes or property surveys.

27.3 MINIMISE POLLUTING MATERIALS OR ACTIVITIES

Where practicable, site users should be encouraged to use materials and undertake activities likely to pose the lowest risk to the receiving environment. This not only helps to keep potential disposal, storage and other pollution problems to a minimum, but can also be more cost-effective.

For example, landscape and road surface management activities often use chemicals that are readily mixed with rainfall and discharged to the surface water management system, potentially causing damage and pollution. The application of fertilisers, pesticides and herbicides can be used during the operational life of the SuDS, if used appropriately and proportionately, having evaluated the risks and provided appropriate mitigation.

De-icing agents can also pose risks, particularly where they are mixed with sand (causing more solids wash-off, which is not desirable). However, calcium magnesium acetate, potassium acetate, or similar materials, cause less adverse environmental impact than urea and sodium chloride in de-icing materials.

Consideration of rates of application of de-icing materials onto road surfaces should form part of the risk management approach and should always follow best practice guidance.

Best practices for painting, resurfacing and resealing of roads, pavements, fencing or other public space infrastructure should be followed to minimise risks.

The wash-off from vehicle cleaning should not be discharged into the surface water system. Solvents and cleaning products should be avoided, where there is a risk that the cleaning water could mix with surface water runoff. The use of cleaning products and potentially harmful chemicals should always be controlled, and eliminated where possible.

Products labelled as biodegradable can still be harmful to the environment and should not be discharged to a surface water drainage system.

Consideration should be given as to whether polluting activities can be undertaken less frequently or done over shorter periods of time. For example, raw materials could be delivered to a site closer to the time of use, reducing the need for stockpiling and exposure to the weather.

27.4 PREVENT POLLUTANTS MIXING WITH RAINFALL

Where practicable, the site should be designed and used in such a way as to minimise pollutants mixing with rainfall. There are a number of actions that can help to achieve this. Examples are provided in the following subsections.

27.4.1 Cover the polluting activity

Covering sources of pollutants can prevent their mobilisation with rainfall, and activities with a high pollutant risk should not take place on areas discharging to the surface water drainage system.

Vehicle washing areas can be covered (roofed) or can be designed to use dedicated wash-bays discharging to the foul sewer. The drainage for the site can also be designed to prevent rainwater entering these areas and contributing to the discharge to the foul sewer.

Liquids arising from areas such as fuel delivery and refuelling areas; vehicle loading or unloading zones where potentially polluting materials are handled; oil/chemical storage, handling and delivery areas; and stockpiles of soil and other waste products should be collected, contained and disposed of safely.

Unloading and storing containers with chemicals beneath a covered loading bay or canopy, for example, would reduce the risk of spills polluting runoff, but appropriate ventilation and fire precautions would need to be implemented.

27.4.2 Contain and separate pollutants

The use of materials that can cause significant pollution risks may require facilities to contain any spillages, such as bunding of oil and chemical storage areas, trays and liners. These should be specifically designed to suit the facility and operation.

Site owners should always ensure that solid and liquid wastes are disposed of appropriately. There are generally four options for disposal, depending on the type of waste and concentrations of the associated contaminants. These should be considered in order of preference:

- recycling facilities
- municipal solid waste disposal facilities
- hazardous waste treatment, storage and disposal facilities
- foul sewer treatment facilities.

Many liquid wastes can be discharged to a foul sewer, subject to approval from the sewerage undertaker. If wastes cannot be legally discharged to a foul sewer, one of the other three disposal options (listed above) should be used. Surface water runoff should never be drained to the foul sewer due to risks of overloading.

Sumps or holding tanks may be useful for storing liquid wastes temporarily, but the contents must then be disposed of properly. Dangerous and hazardous wastes must be transported to an appropriate hazardous waste disposal, treatment or storage facility.

Where solid wastes are stored outdoors on site, including recycling waste that is contaminated, then runoff from these areas will need to be treated specifically to manage the pollution risk before discharge to the surface water drainage system.

Walton (2014) provides guidance to assist owners and operators of industrial and commercial facilities in storing substances that may be hazardous to the environment.

An example of containing the supply of pollutants is the implementation of a street sweeping and/or gully inlet/silt trap emptying regime. Such strategies are known to be effective at limiting pollution by capturing and disposing of dust and debris before it enters the surface water management system. General control of litter and other solids, including leaf fall, is also important for a range of urban surfaces, not only streets.

In some scenarios, light liquid/oil/petrol separators may be appropriate for managing low levels of hydrocarbons from, for example, car parks (BS EN 858-1:2002 and BS EN 858-2:2003). All trapped materials should be recycled, where practicable.

▶ Guidance on proprietary products that separate out oils, sediments and other contaminants is provided in **Chapter 14**.

27.4.3 Manage the pollutant conveyance pathway

Locating potentially polluting activities away from runoff routes will reduce the chance of pollutants mixing with surface water flows. For high risk areas, such as where chemicals are being handled, the provision of flow diversion or cut-off structures, along with instruction notices, can help prevent polluted runoff from entering the surface water drainage system.

Activities located far from known overland runoff routes are less likely to pollute surface water runoff. It will take longer for the pollutants to mix with the runoff and drain into the SuDS components, allowing more time for a response to a spill. Depending on the location of the activity, this may be sufficient to allow substantial clean-up of the area around the activity.

Regardless of the location of the activity, protection of groundwater is crucial, so environmental protection best practice and prompt responses to spills are always important in order to prevent pollution, even in dry weather.

27.4.4 Prevent spills and provide appropriate clean-up

Spills can contribute a variety of pollutants to surface water runoff and are often preventable, if appropriate practices for chemical and waste handling and spill response are implemented. A spill can be a one-off event, a continuous leak or frequent small spills. All types of spill should be addressed.

Leaks and spills of solid or liquid pollutants (including oils, solvents, fuels and dust from manufacturing operations) should be contained promptly, and an appropriate clean-up regime implemented. Appropriate spillage/clean-up kits should always be available, and operational measures may require emergency teams and procedures for responding in the event of a spill incident. This should include due consideration of motor vehicle accidents and vandalism, where appropriate. Spill risks should also be considered during the construction phase and appropriate procedures put in place.

Where a site is deemed to be at risk from catastrophic events, such as a major explosion, this should be taken into consideration, as these can cause acute pollution. There is renewed emphasis on planning for potentially catastrophic events and these are considered further in Gilbertson *et al* (2011) and ISO 31000:2009.

27.4.5 Move the activity elsewhere

If the above options are too onerous, one alternative is to consider moving the polluting activity off site, and to use a dedicated facility elsewhere.

27.5 PROVIDE EDUCATION AND TRAINING

All businesses operating on sites drained by SuDS should set up and document regimes for site pollution prevention best practice, based on the guidance provided above.

Staff on commercial and industrial premises should be aware of the site pollution prevention strategy, and the operational procedures required to minimise the risks of causing water pollution and the associated legal consequences.

Improving public understanding of the operation of surface water drainage systems and the potential for water pollution using education and information can encourage pollution prevention. Such campaigns can be initiated by the owner of the surface water management system or by a partnership that includes environmental regulators, local authorities and/or other environmental groups. The impact of dog fouling, vehicular washing and the disposal of wastes (eg paints, solvents) to surface water drains should be explained, along with recommendations for alternative forms of disposal. Public education strategies can also promote the benefits of using environmentally friendly substances (**Section 27.3**).

Signs that highlight the possible impacts, either at or near the SuDS, or at inlet locations, are an effective means of raising community awareness of pollution. The Environment Agency and SEPA promote the Yellow Fish campaign (EA, 2012a and 2012b) as part of their Healthy River Code (EA, nd), for use in public engagement and business and contractor education strategies (**Figures 27.1 and 27.2**).

Figure 27.1 Examples of signage that can be used on public drains (courtesy Drain Markers)

Figure 27.2 Example of the type of information that can be used in public campaigns (courtesy Love Your River)

27.6 REFERENCES

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STATUTES

British Standards

BS EN 858-1:2002 *Separator systems for light liquids (eg oil and petrol). Principles of product design, performance and testing, marking and quality control*

BS EN 858-2:2003 *Separator systems for light liquids (eg oil and petrol). Selection of nominal size, installation, operation and maintenance*

ISO

ISO 31000:2009 *Risk management – Principles and guidelines*

Image courtesy Robert Bray Associates

28 INLETS, OUTLETS AND FLOW CONTROL SYSTEMS

Contents

Chapter 28 Inlets, outlets and flow control systems

This chapter provides guidance on the design of inlets, outlets and flow control systems. Inlets and outlets are the structures or landscape features that convey the flow into and out of a SuDS component. Control structures limit the flow through the outlet of a SuDS component.

▸ *Guidance on good landscape practice is discussed in Chapter 29.*

28.1 INTRODUCTION

Inlets and outlets are the structures or landscape features that manage the flow into and out of a SuDS component. Control structures limit the flow through the outlet and are usually necessary in order to meet the site discharge rate. Limiting the flow causes water to back up in the SuDS component, allowing the attenuation storage volume to be filled.

There is a wide variety of different types and styles of structure/feature available, and they can be designed to add interest and character to an urban setting, or to blend into a natural landscape.

The suitability of different types of inlet or outlet will often depend on the type of component they are serving and the processes it supports. In some cases, the type of component (eg permeable pavements or attenuation tank storage systems) or the constraints of a site, will lead to the use of below-ground control structures (sited in access chambers, commonly adapted from standard inspection chamber specifications for non-man-entry and standard manhole specifications for man-entry access).

Where a SuDS scheme includes Interception components and manages runoff close to source (**Chapter 4**), velocities tend to be low, and control structures can be small. Keeping runoff on the surface helps keep inlets and outlets shallow, visible and cost-effective. Headwalls and abutments should be as small as possible and can be designed using local materials, such as local stone, local bricks, timber etc. Where concrete is used, it can be textured or clad to add interest and blend more effectively with nearby natural features. Sympathetic planting around the structures can help with their integration into the landscape, but this should not impede operation or obscure their easy viewing, for inspections. Planting can also be used to help prevent erosion, using planting mats and other bioengineered materials that are often deployed for channel bank protection. Other options include using stone or other rip-rap materials for energy dissipation.

In all cases, the hydraulic, structural and geotechnical design of inlet and outlet structures should be undertaken by designers with appropriate technical/engineering expertise. Guidance on sizing is provided in this chapter, but textbooks, such as those by Chow (1959) and Henderson (1966), should be referenced for detailed theory relevant to the hydraulic design, where necessary.

courtesy Illman Young

courtesy Robert Bray Associates

Figure 28.1 Examples of inlet/outlet systems

28.2 GENERAL DESIGN CONSIDERATIONS

Flow is conveyed to, from and between SuDS components in open channels, across vegetated surfaces or within pipework. The definition of flow structures used in this chapter is as follows:

- An inlet structure conveys flow into a SuDS component.
- An outlet structure conveys flow out of a SuDS component.
- A control structure restricts the rate of flow into or from an outlet structure.

The details presented in this chapter for erosion control measures downstream of an inlet structure may also be adapted by the designer for outlet structures where they discharge into receiving waters downstream.

The following issues should be considered when designing inlet and outlet structures:

- simplicity of operation
- resistance to clogging, blocking or mechanical failure
- local landscape characteristics
- cost and ease of construction
- accessibility, visibility, cost and ease of maintenance

- longevity and reliability
- health and safety with respect to construction, operation and maintenance.

Surface control structures such as simple orifices (small diameter holes) or slot weirs are usually relatively easy to maintain, provided they are visible and accessible. Below-ground systems will usually need to have a cover lifted for inspection, and may therefore be overlooked or forgotten about. The risk of this should be assessed by the designer, and an appropriate risk management approach adopted for the site. On large managed sites the maintenance of buried structures is rarely a major issue. However, the system should be designed so that, if it does become blocked, it is apparent on the surface before it poses a significant risk. Small discrete features in the landscape can also be overlooked if they become hidden by vegetation or debris.

Where any pond or basin is regulated under the Reservoir Act 1975 as amended by the Flood and Water Management Act 2010; that is, it can hold > 10,000 m^3 of water, the inlet and outlet designs must meet the requirements of this legislation. Any structure discharging into a watercourse or culverted watercourse will need consent from either the environmental regulator, lead local flood (or drainage) authority or the internal drainage board, and any relevant byelaws should be taken into account, where relevant.

▶ Health and safety risk management design guidance is provided in **Chapter 36**.

28.3 INLET AND OUTLET LAYOUT

SuDS components can generally be divided into three zones:

1. **inlet zone** – includes appropriate design for velocity reduction and effective flow distribution across the width of the SuDS component and may also include a sediment trapping and storage area
2. **main treatment, storage and/or conveyance area**
3. **outlet zone** – may be deeper than the main area to prevent resuspension of sediments, or may be designed with a raised outfall to encourage enhanced infiltration, filtration and/or other treatment processes before discharge.

In order to maximise the effectiveness of treatment processes between inlet and outlet, short-circuiting should be avoided – that is dead treatment storage areas (areas within the system that are bypassed by the normal passage of flow and are therefore ineffective in the treatment process) – should be minimised. Examples of poor and improved configurations are presented in **Figure 28.2**. Where design shapes are fixed and not ideal, baffles may be used to help lengthen flow paths.

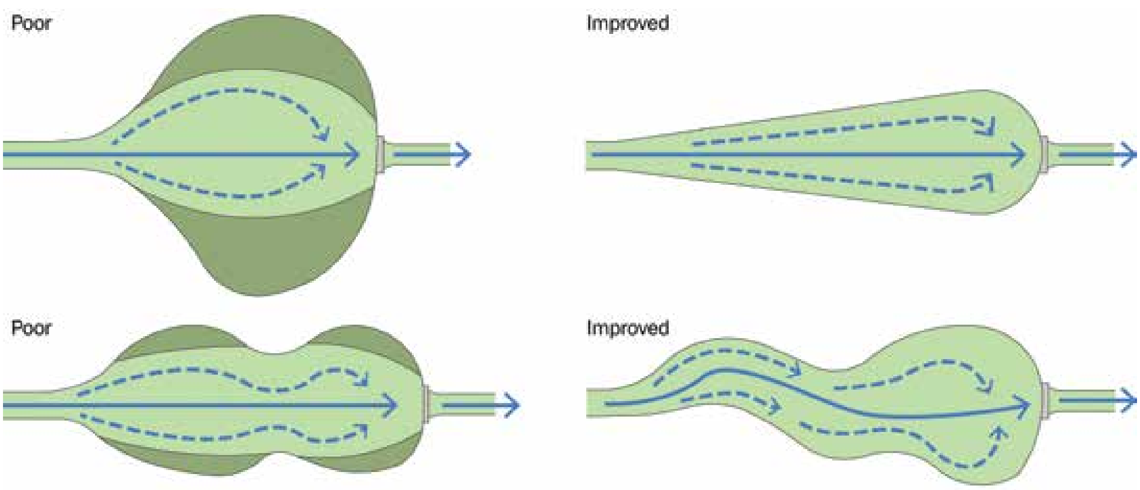

Figure 28.2 Examples of poor and improved inlet and outlet configurations

28.4 INLET SYSTEMS

The mechanism by which runoff is collected and delivered to a SuDS component will vary, depending on the component type, site layout, topography and flow paths. Pervious pavements and green roofs collect runoff directly without the need for inlets. Filter strips, filter drains and swales should generally receive runoff via lateral inlet systems that distribute the flow along a continuous or semi-continuous length. Point inlets from piped collection systems are usually required for inflows to ponds and detention basins. Runoff will often be discharged into bioretention systems, and some swales via gaps or holes in kerbing. There will always be other site-specific scenarios that will require the modification of standard inlet configurations, such as the delivery of roof water into a pervious pavement sub-base, and the introduction of water into swales via point source inlets.

28.4.1 Inlet design

All inlets should be designed to meet the following requirements:

- deliver the required maximum flow rate freely from the upstream collection system
- be as simple as possible (taking into account the characteristics of the site and the level of management)
- be easy to construct
- be structurally robust
- functionality is clear and obvious for those who will maintain them and for the local community (where appropriate)
- be easy and convenient to maintain (eg easily accessible for the required operations, and requiring maintenance frequencies that align with the site landscape maintenance requirements)
- have low risk of blockage
- have low risk of erosion
- have low risks to people (eg no open pipework accessible to small children)
- have low risks to wildlife, taking into account the site-specific characteristics and likely biodiversity (eg no exposed sumps, traps, gullies or open inlets to sewers)
- be visually interesting or neutral (ie no negative aesthetics)
- have low risk of vandalism
- be cost-effective.

Specific inlet details for each SuDS component are set out in individual chapters (**Chapters 11–23**). This chapter presents generic concepts, together with hydraulic control principles.

28.4.2 Point inlets

Components of a standard, small piped inlet system are likely to comprise:

1. **conveyance pipe** of suitable diameter to allow unrestricted flow, laid to appropriate fall, with bedding and surround
2. **inlet protection** to the pipe, such as a small concrete surround, a small headwall, stone-filled baskets or gabion protection
3. **erosion control** (if required) such as concrete, stone or sett pad, rip-rap or other apron device to reduce energy within the inflow that may damage the SuDS component surface and/or planting
4. **flow spreading** (if required) such as a horizontal sill or low berm to prevent flow channelling and maximise treatment efficiencies of vegetated surfaces.

Inlet design should recognise the source of the upstream flow. Where the surface water runoff is discharged from a filter drain, or pervious pavement, it will be free from any debris or sediment that might need to be removed, and therefore a grille or stone protection for the inlet would be acceptable. Where water is collected from an open system, such as a swale or hard surface, there is always a risk that silt, litter or vegetation could block the pipe, and so ease of maintenance is fundamental to the design.

Inlets raised above any adjacent permanent water levels are generally recommended. Submerged inlets have the following potential risks:

- surcharging or backwater effect on the upstream surface water conveyance system
- scour/resuspension of the component base near the inlet
- clogging of the inlet by sedimentation near the inlet
- sediment deposition in the upstream conveyance system.

Also, all concealed infrastructure is likely to be at risk from blockage or lack of maintenance.

Hard engineered erosion protection systems can often be replaced by deep pools and planted berms. Pools dissipate energy and moderate velocities, which in turn help to limit the resuspension of accumulated sediments. Planted rock berms can create low weirs that are resistant to breaching and allow debris to accumulate upstream. Where regular sediment removal is likely to be required such as within a forebay, a concrete base may be appropriate.

Examples of current good practice are shown in **Figure 28.3**.

Where high flows are unavoidable and larger diameter pipes are involved, concrete, brick or stone head walls may be required. There may also be a need for safety/security screening of pipe outfalls. In such situations, the hard surface should be carefully integrated with the adjacent landscaping to enhance aesthetic impact, minimise safety risks (eg trip hazards) and facilitate maintenance. Such structures should be very carefully designed if they are to be acceptable from a maintenance, amenity and sustainability perspective. Vertical concrete faces on outlets, in particular, tend to exacerbate blockage risks (this is not an issue on inlets) and large vertical drops can easily pose a health and safety risk, which is generally not effectively mitigated through the use of fencing. Siting planting beds above inlets can help to disguise them from above, while still allowing access from below and may reduce the need for fencing.

Erosion control systems and more formal energy dissipation devices for inlets are described in **Section 28.4.6**.

28.4.3 Lateral inlets

Where runoff is draining laterally from an impermeable surface and is collected by a SuDS component running along its edge (eg filter strip, swale, filter drain or bioretention system) the collection mechanism should provide an appropriate edge detail to the pavement, which allows the transfer of runoff to the SuDS and minimises the risk of flow "channelling" that can cause deterioration in performance or failure of the downstream SuDS.

It is important that grass growth is robust at the edge of the detail to prevent erosion of the SuDS surface. This will generally require topsoil depths of 100–150 mm, which may mean that kerb depths need to be increased, or a revised edging detail used. Also, the receiving grass surface should be 20–30 mm below the kerb edge, so that the runoff can discharge freely and there is no risk of sediment accumulation blocking the flow path (**Chapter 9**).

Gravel strips or tactile paving blocks can also be used to pre-filter and spread the flow downstream of kerb edges. Silt is collected within the gravel strips, although such strips (eventually) tend to only act as flow spreaders as the silt cannot easily be removed during operation and maintenance activities.


courtesy Illman Young


courtesy Illman Young


courtesy Robert Bray Associates


courtesy Robert Bray Associates


courtesy pallesh+azarfane


courtesy Illman Young


courtesy Aco Limited


courtesy Graham Fairhurst


courtesy Robert Bray Associates

Figure 28.3 Examples of low-flow inlet pipes and channels to SuDS components

courtesy Arup/Giles Rocholl Photography

courtesy Ecofutures

courtesy Hydro International

courtesy Robert Bray Associates

Figure 28.4 Examples of high-flow inlet pipes to SuDS components

28.4.4 Kerbless and flush kerb designs

Kerbless road designs allow surface water runoff to flow directly from the impervious surface to the SuDS component. This type of design discourages flow concentration and reduces flow velocities.

The structural integrity of kerbless and flush kerb design needs careful consideration in order to prevent deterioration of the surface edging (and potential collapse) due to traffic movements etc. Moving of the surface edge can end up preventing runoff from flowing off the surface into the SuDS component. Where there are particular risks of significant traffic movement at the surface edge, the surface edging should be strengthened or alternative designs considered.

28.4.5 Kerb openings

Where flow is to be introduced via kerb openings, the dimension of any kerb opening should provide a sufficient width of flow to minimise risks of erosion, channelling or blockage (300–400 mm is normally sufficient where inflow paths are straight, but 600 mm should be the minimum where the flow direction is at an angle to the inlet aperture. The edge should be flush with the runoff surface to prevent ponding and sedimentation.

Surface water can also be collected using gully or kerb collection systems that convey the water to downstream treatment, conveyance and/or storage components.

Figure 28.5 Timber sleeper edging with gaps, University of York (courtesy Arup/Giles Rocholl Photography)

courtesy Robert Bray Associates   courtesy Robert Bray Associates   courtesy Illman Young

Figure 28.6 Roadside lateral inlets

Figure 28.7 Kerb collection system being used to drain a carriageway in conjunction with a swale (courtesy ACO Limited)

28.4.6 Flow spreaders and energy dissipation

For lateral collection systems, flow spreading is required to ensure even distribution of flows (in case upstream flow paths have been distorted or concentrated) and is usually achieved using a level sill (kerb or concrete section), a gravel strip (gravel diaphragm) or a shallow channel.

For point inflows, flow spreaders are designed to distribute concentrated flows over a larger area to reduce flow velocities, thereby controlling erosion risks and maximising the treatment effectiveness of the receiving SuDS component. There are many types of spreaders that can be selected, based on the rates of inflow and site characteristics.

However, their generic design objectives should be:

- concentrated flow enters the spreader at a single point such as a pipe, swale or kerb opening
- the flow is slowed and energy is released
- the flow is distributed.

The following considerations are important when designing and constructing flow spreaders:

1. It is critical that any edges over which flow is distributed are exactly level. If there are even small variations in height on the downstream lip, small rivulets will form, and experience suggests that variations of more than 3 mm can cause water to re-concentrate and potentially cause erosion.
2. The downstream side of the spreader should be clear of material (usually achieved by the downstream side being at a lower elevation), otherwise flow paths can be blocked.
3. The vegetated surface downstream of the spreader should be fully stabilised before the spreader is used, else erosion rills will quickly form.
4. Flow spreaders should not be considered to be sediment removal facilities themselves, although they can be combined with forebays of, for example, smooth concrete where sediment can be collected.

The Priors Farm inlet (shown in **Figure 28.8**) uses raised granite sets and the planting has been designed to contribute to flow spreading and dissipation when established.

Priors Farm, Cheltenham (courtesy Illman Young)

Bottesford retrofit rain gardens (courtesy North Lincolnshire Council)

Figure 28.8 Examples of flow spreading/energy dissipation inlets

28.4.7 Bypass structures and flow dividers

Bypass structures can be used to divert flows above a threshold into a bypass pipe or channel or directly into another SuDS component, providing greater attenuation storage than the main flow route (for example, as shown in **Figure 28.9**). The same configuration could be used to bypass volumes of runoff from extreme events into a Long-Term Storage or exceedance storage area.

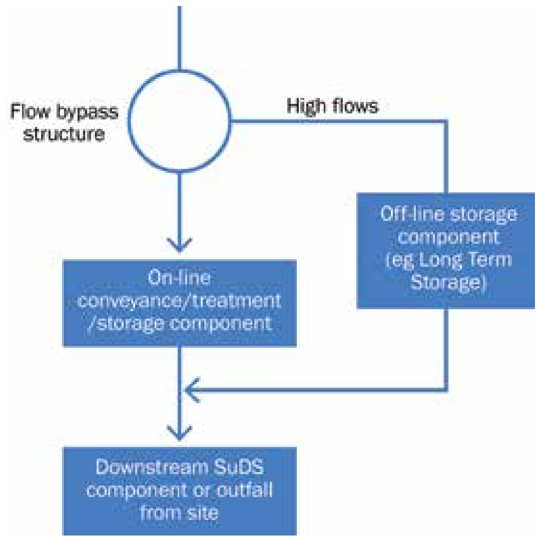

Figure 28.9 Requirements for flow bypass structures

In such cases, the inlet structure will normally include a means of controlling the flows that pass to the SuDS component. The complexity of the structure will depend on the level of flow control required. A crucial factor in designing flow dividing structures is to ensure that the correct low flow is retained on the main drainage path and that, above this rate, extra flows are diverted with minimal increase in head at the bypass structure to avoid surcharging the main drainage path under high flow conditions.

For surface flows, flow diversion structures can often be constructed through the use of appropriate landscaping alone; for example, for an off-line detention basin it may be possible to spill high flows over a low section of a channel bank into the detention basin, without any control on the flows passing on down the channel other than the channel capacity itself. **Figure 28.10** illustrates such a system, with low/medium range flows passed downstream to a treatment wetland.

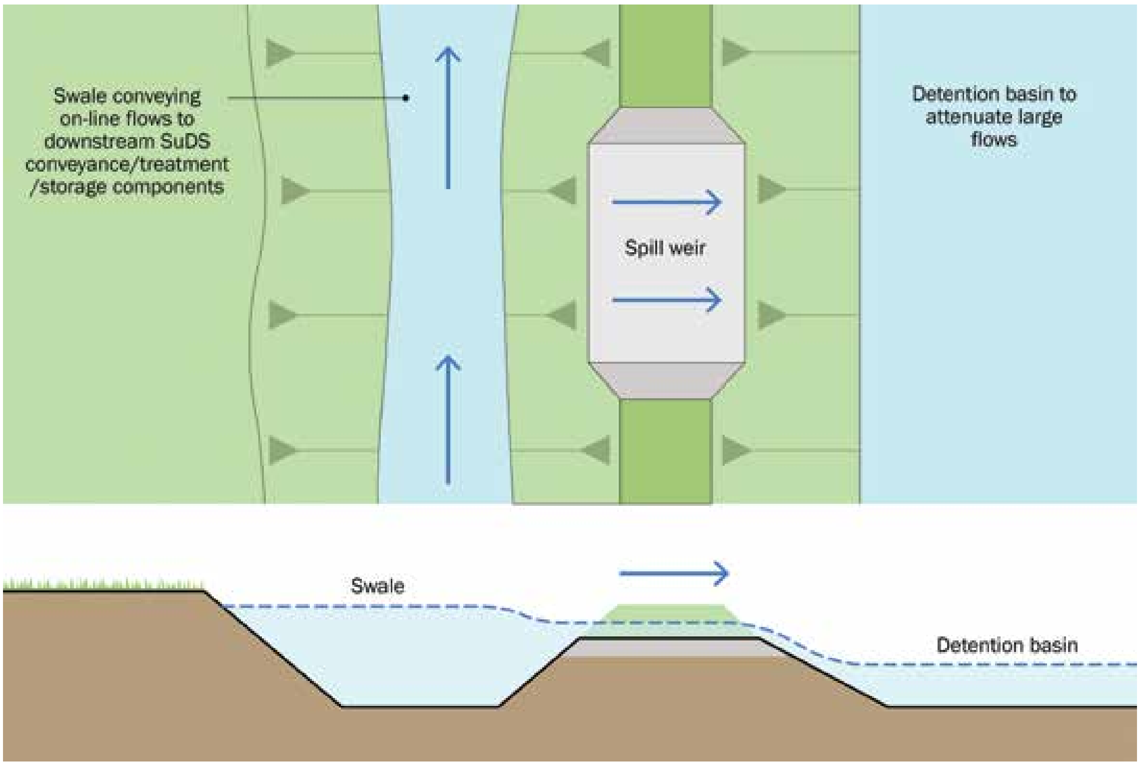

Figure 28.10 Simple overflow inlet to detention basin; no restriction on flow passed downstream as shown but could be combined with a flow control

Protection may be needed for the weir crest and face of the detention basin to prevent erosion from the flow. This has taken the form of bioengineered grassed surfaces in some sites where flows are low. Other solutions that have been used are thin gabion mattresses or small cellular concrete blocks allowing the development of partial grass cover, although, for occasional periods of discharge, a well grassed surface is likely to be adequate. The design of grass-lined spillways has been documented in Hewlett *et al* (1987).

Figure 28.11 Example of landscaped flow splitter structure, River Chelt (courtesy Illman Young)

For piped flows, and where flows need to be tightly controlled, a "harder" structure may be required. This scenario is likely to be relevant only for heavily urbanised, high density development where the majority of the drainage infrastructure has to be below ground. Maintenance and safety issues should always be given full consideration.

Engineered manhole flow dividers are likely to comprise one or two chambers with pipe or weir outlets (**Figure 28.12**).

In cases where the normal and higher flow outflow routes from the chamber(s) are both via pipes, it is also advisable to include an "emergency" high-level weir, designed to deal with extreme return period flows and also to pass flows in the event of blockage of the pipe(s). The emergency weir may pass extreme flows to a detention basin, or a bypass route, or possibly both.

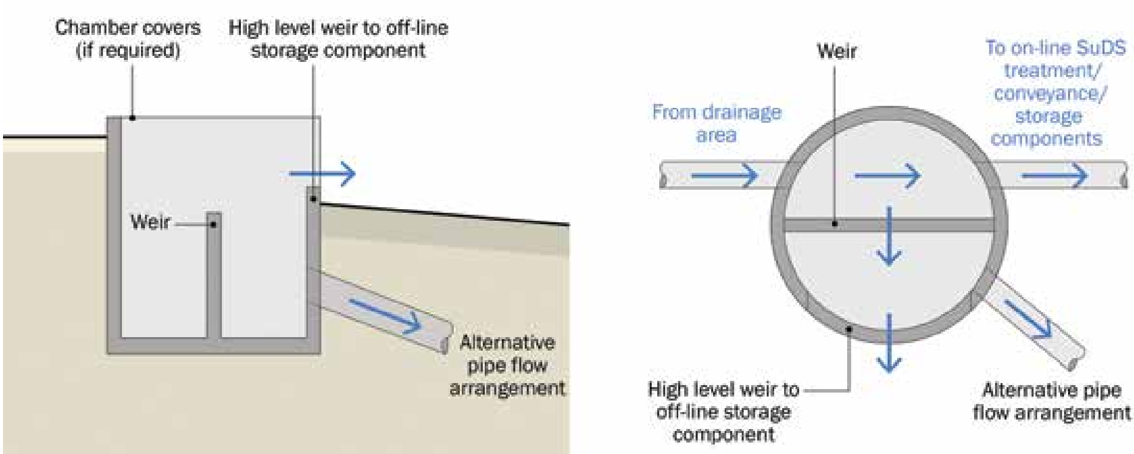

Figure 28.12 Conceptual design for engineered inlet flow divider

The key requirement of the hydraulic design of the inlet structure is the need for appropriate design and sizing of the pipes and weirs to achieve the required discharge relationships, including the derivation of appropriate threshold water depths and levels that are compatible with the available hydraulic head.

There may be more than one inlet to a pond or detention basin. In such cases, consideration needs to be given to whether the economic and functional requirements can be more effectively met by either combining the incoming pipe systems upstream of any inlet flow divider or by providing a number of separate inlet divider structures. Care needs to be taken to ensure that there is no opportunity for any adverse short-circuiting between the outlet and the nearest inlet. It is recommended that, where such systems have to be implemented, they are kept as simple as possible.

28.4.8 Sediment detention (sediment trap or forebay)

Effective pre-treatment should ideally be implemented via appropriate upstream SuDS Management Train components (**Chapter 26**). Where there are residual sediment risks, or where a sediment forebay is the only suitable management option at the site, then SuDS components can be split to delineate specific areas where sediment removal is specifically facilitated. Sediment detention may either be undertaken in a separate basin or pond, or within a sediment detention area that is part of a SuDS component. A sediment trapping area allows sediment build-up to be easily monitored, and any required sediment removal activities are concentrated within a small area, thereby minimising potential damage to other SuDS areas (**Chapters 11–23**).

▶ Sediment waste management is discussed in detail in **Chapter 33** and in individual component chapters.

If the sediment deposition area is designed to be intermittently dry, this will aid biodegradation of organic pollutants. Planting can be used to screen and/or enhance sediment deposition areas.

Where a sediment detention facility can only be included within a pond or wetland, a simple approach is to include a weir or bank across the pond. The design will depend on the depth and configuration of the basin, but the following approaches should normally be considered (either singly or in combination) to separate the sediment basin from the rest of the pond:

1 permeable weir, such as gabions, through which low flows would normally pass, but allowing overflows for larger events

2 earth embankment, designed to overtop and protected accordingly

Appropriate access should always be provided to allow removal of accumulated sediment.

28.5 OUTLET STRUCTURE (OUTLETS AND FLOW CONTROL SYSTEMS)

Outlet structures convey and control the flow out of the SuDS components and, therefore, determine the ability of the system to manage both low and high flows. Outlets can either be on the surface (open channels built into the visible edge of the component), piped systems (conveying water through the edge of the component) or slow seepage systems (conveying water slowly through a porous medium).

Low return period flows are normally controlled with smaller, often protected, outlet structures, such as orifices located within screened pipes or risers, perforated plates or risers, small pipes, reverse-slope pipes and V-notch weirs. Larger flows are typically controlled using overflows, such as flows over a weir within a manhole or across a spillway/weir through an embankment. Overflow weirs can be of varied heights and configured to handle control of multiple design flows.

Vortex flow control systems can also be used to manage a range of flows (**Section 28.5.7**).

Outlets are usually built into the downstream bankside of SuDS components with easy access for maintenance.

For piped systems, a box or manhole outlet structure downstream of the outlet can accommodate a variety of flow control mechanisms, although the depth of such structures should be considered carefully in the context of access, ease of maintenance and confined entry requirements. Any pipe bedding and/or surround material can be a conveyance route, and where flow controls are included within the design, impervious fill/protection against seepage is required.

Similar techniques to those described for inlets can be employed to integrate outlet structures into the overall landscape. Natural stone and plant material can be used in place of concrete and hard structures to meet aesthetic, amenity, ecology and sustainability objectives. Any outlet design should minimise the risk of clogging and blockage, and their siting should allow access for ease of maintenance.

28.5.1 Outlet system design

The sizing of outlet structures is typically a process where iteration is used to refine the design details. A stage discharge curve is usually established for a given outlet design. Then calculations are undertaken or a model is run to determine whether the peak outflow for a range of return periods flows is adequately controlled.

A key step is to identify clearly the duties that the structure needs to perform and therefore the components that need to be included. **Table 28.1** gives a broad indication of the principal components that may be required. In general, outlet structures should be designed to be as simple as possible to construct, operate and maintain. The main concern for all outlets should be minimising the risk of blockage.

In the following sections, a range of outlet systems are described that are generally appropriate for maximum water depths of up to about 2 m. SuDS designs should not involve greater depths of water. However, should larger structures be required, designers should follow the guidance given in Hall *et al* (1993), which contains a comprehensive account of the types of control structures that may be deployed for the outlet structures of on-line and off-line flood storage reservoirs.

28.5.2 Orifices

An orifice is a circular or rectangular opening of a prescribed shape and size that allows a controlled rate of outflow when the orifice is submerged. When it is not submerged, the opening acts as a weir. The flow rate depends on the height of the water above the opening (hydraulic head) and the size and edge treatment of the orifice. When using a simple orifice plate, the flow rate passing through the control is directly proportional to the square root of the upstream head (**Equation 28.1 and Figure 28.13**), so as the water level increases, the flow also increases steadily.

TABLE 28.1 Typical outlet system components

Component	Description
Flow control device	For most SuDS components, this will normally comprise a fixed orifice, V-notch weir or an alternative form of throttle such as a short pipe, culvert or vortex flow control with similar hydraulic characteristics. Its principal function is to throttle the discharge passed downstream and thereby enable the attenuation storage volume to fill.
Exceedance flow overflow weir	This provides the flood discharge route from the component when the available flood attenuation storage capacity has been filled. The weir and the flow route downstream are normally designed to pass a flow of a particular design return period. In the case of an off-line SuDS component, an overflow weir may not be required if the inlet structure is designed in such a way that flows are reliably bypassed whenever the pond or basin is full. In some cases, it may be appropriate to combine the function with the emergency spillway.
Emergency spillway	The emergency spillway provides the ultimate safeguard against uncontrolled overflows. It may be the same structure as the overflow weir. A shallow grass weir with inclined slopes and suitable erosion protection is often sufficient.

If a variable greenfield flood frequency curve is specified, this type of response may be appropriate, although multiple orifices may still be required to meet multiple return period requirements. Orifices can be used for above-ground or below-ground systems and can also be used to control flows from underdrainage components.

Orifices act as very efficient throttles (flow constraints), and this efficiency can be disadvantageous in some respects in that it may put water into storage early in the storm, while the downstream channel still has the capacity to accept it.

Orifices may be constructed in a wall or baffle, in perforated risers, or as a T-piece section such as that shown in **Figures 28.14 and 28.15**. With the inlet set below the water surface, T-pieces help to reduce the risks of blockage and, in particular, the chance of oils being transported downstream.

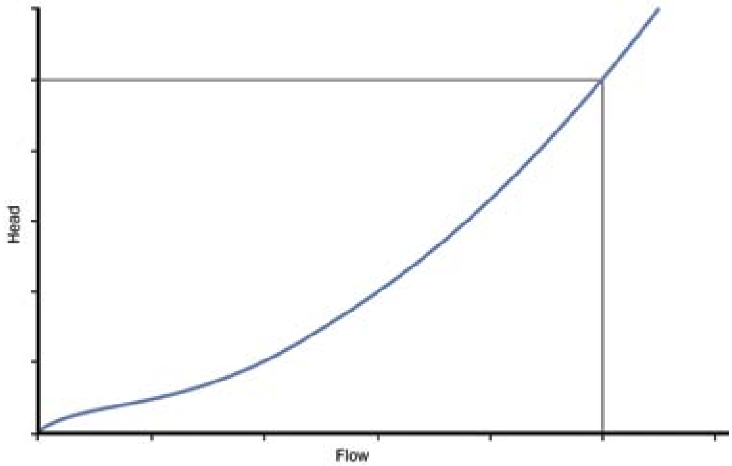

Figure 28.13 Head–discharge relationship for a simple orifice plate (courtesy Hydro International)

For a single orifice, the orifice discharge can be determined using the standard orifice **Equation 28.1**.

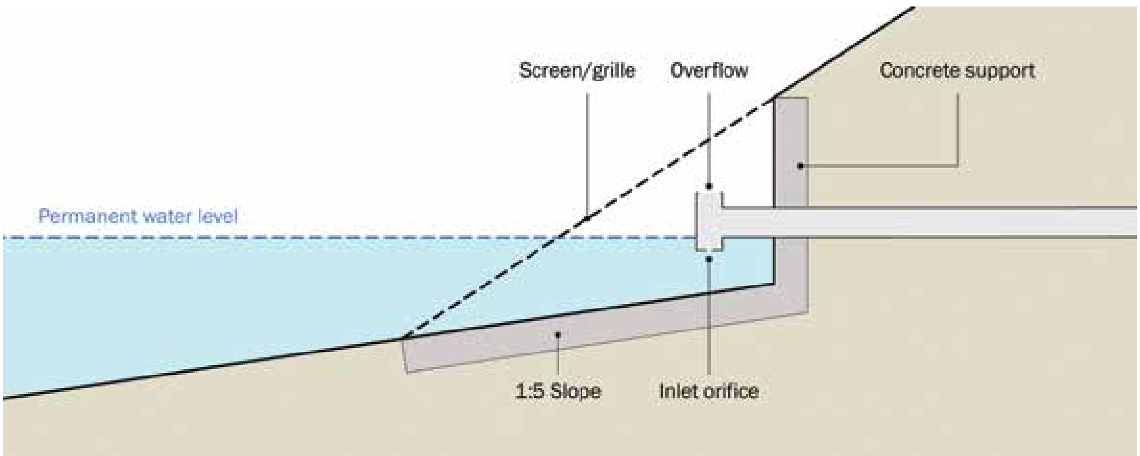

Figure 28.14 T-piece orifice structure with pipe base providing permanent water level control

Figure 28.15 Example of screened orifice outfall with T-piece structure (courtesy Robert Bray Associates)

EQ. 28.1 **Standard orifice equation**

$$Q = C_d \, A_o \sqrt{2gh}$$

Where:

Q	=	orifice discharge rate (m^3/s)
C_d	=	coefficient of discharge (m) (0.6 if material is thinner than orifice diameter; 0.8 if material is thicker than orifice diameter, 0.92 if edges of orifice are rounded)
A_o	=	area of orifice (m^2)
h	=	hydraulic head (m)
g	=	9.81 m/s^2

When the orifice is discharging as a free outfall, the effective head is measured from the centre of the orifice to the upstream (headwater) surface elevation. If the orifice is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces, as shown in **Figure 28.16**.

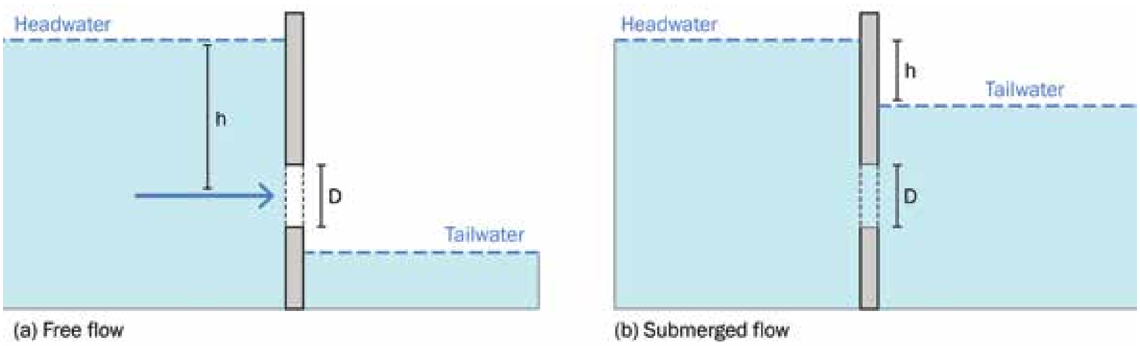

Figure 28.16 Effective head for orifice discharge calculations

Exposed orifices with diameters similar to tennis balls and soft drink cans are particularly vulnerable to blockage. Perforated risers with protected orifice plates can be used to minimise blockage rates for very low flow controls (**Section 28.5.3**). Other outlet protection systems are described in **Section 28.5.10**.

Flow through multiple orifices, such as the perforated plate shown in **Figure 28.17**, can be calculated by summing the flow through individual orifices. For multiple orifices of the same size and under the influence of the same effective head, the total flow can be determined by multiplying the discharge for a single orifice by the number of openings.

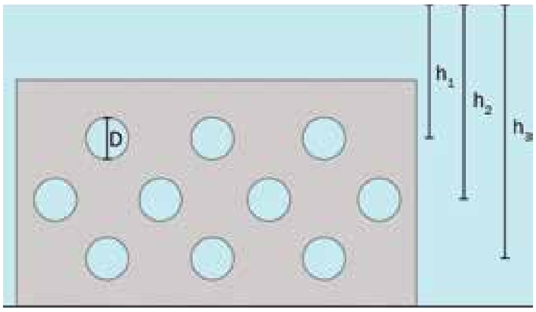

Figure 28.17 Multiple orifice plate

28.5.3 Perforated risers

Perforated risers can be used in the following forms:

1. in conjunction with orifice plates as a mechanism to protect against blockage; in this scenario, the perforations in the riser should convey more flow than the orifice plate, so as not become the control
2. as a more complex flow control structure; in this scenario, each of the orifices on the riser will contribute to the overall head-discharge relationship (**Section 28.5.2**)

A shortcut formula has been developed for estimating the total flow capacity of the perforated section (**Equation 28.2**). The dimensioning is shown in **Figure 28.18**.

EQ. 28.2 **Total flow capacity of a perforated riser (from McEnroe *et al*, 1988)**

$$Q = \frac{C_p \, 2A_p (2g)^{1/2} \, H^{3/2}}{3H_s}$$

Where:

Q = discharge (m^3/s)

C_p = discharge coefficient (for perforations = 0.61)

A_p = cross-sectional area of all holes (m^2)

H_s = distance from S/2 below the lowest row of holes to S/2 above the top row (m)

S = distance between holes (m)

H = head on riser pipe measured from S/2 below the centerline of the lowest row of holes

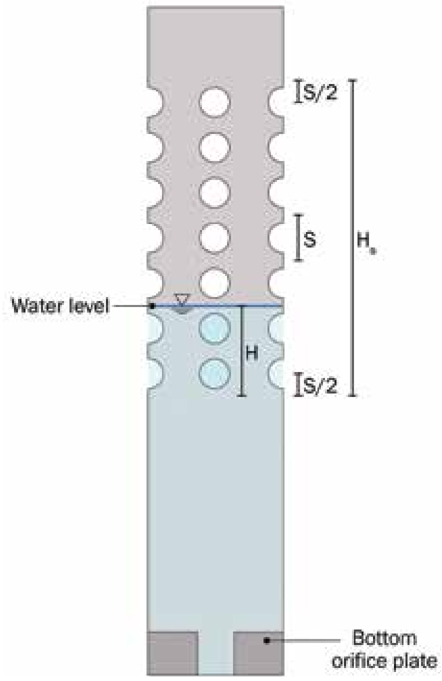

Figure 28.18 Perforated riser dimensions

Figure 28.19 is an example of a perforated riser set in a shallow manhole, with the pipe from the SuDS component to the control structure protected from debris by a gabion basket.

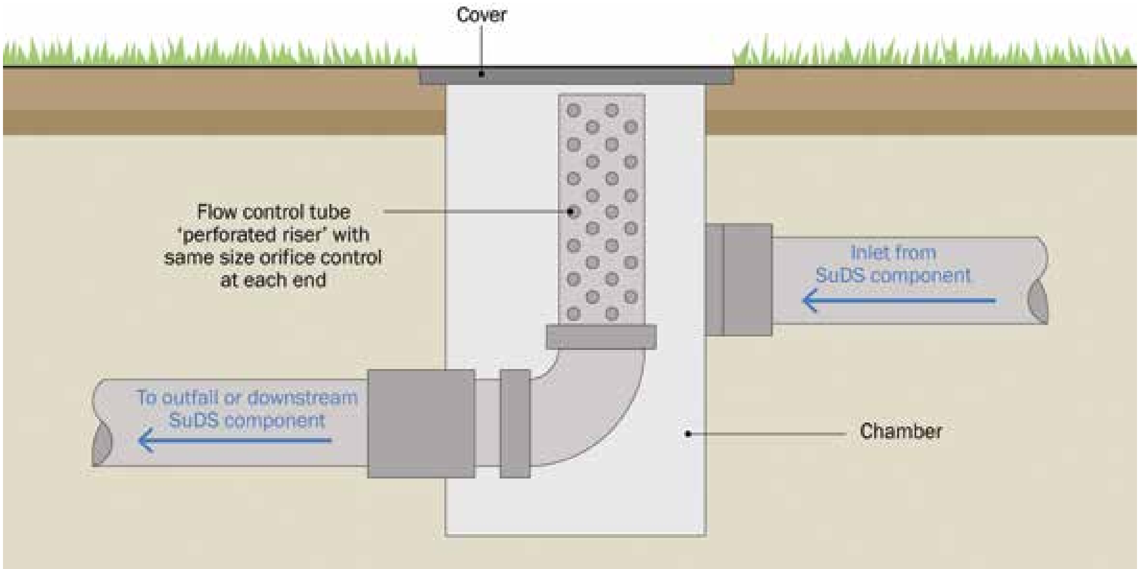

Figure 28.19 Conceptual layout of protected perforated riser outlet structure for small pond (courtesy Robert Bray Associates)

Perforations can become affected by silt or fine particles of vegetation and, if maintenance is not regular, the holes in the riser can become blocked. At worst, water can rise to the top of the tube and overflow into the outfall pipe. The bottom orifice controls the flow up to a 300–400 mm head. The use of a perforated riser tube section with equivalent orifice controls at each end will enable the tube to function correctly, even if it is installed the wrong way round.

Disadvantages of such systems include the requirement for their siting within a subsurface manhole and the potential maintenance implications. There will also be standing water in the manhole between storms up to the outlet level.

28.5.4 Pipes and culverts

Pipes are often used as outlet structures for drainage control facilities and, like the orifice, their head–discharge characteristics mean that they can be efficient flow control systems. During low flow conditions, the pipe head–discharge characteristics are the same as a weir control. As the flow increases, this will transition into an orifice control.

The minimum outlet pipe acceptable for adoption by a sewerage undertaker is normally 75 mm, as required by WRc (2005 and 2012). WRc (2012) gives a minimum opening size for static (fixed) control structures of 100 mm or equivalent. Much smaller diameters may be acceptable for SuDS owned by other organisations, particularly for locations downstream of pervious pavements or other filtration devices where the risk of blockage is very small or at other protected locations. The size of hydraulic controls should always be agreed with the site operator.

Pipes greater than 300 mm can be analysed as a discharge pipe with headwater effects (and tailwater effects if required) taken into account. Reference should be made to standard guidance dealing with pipe flow from Balkham *et al* (2010) and Barr and HR Wallingford (2006).

28.5.5 Weirs

Weirs and notches discharge proportionately more water than orifices or pipes, with an equivalent increase in head. An advantage of weirs is that floating debris will pass downstream and they are not vulnerable to blockage. However, this may be a concern if the component is designed to protect downstream SuDS components from debris. Weirs can be sharp-crested, broad-crested, triangular or of various intermediate cross-sections, each of which has slightly different head–discharge characteristics, depending on the profile, height and area of the opening. Weirs can be used as level and/or flow control structures, and/or emergency spillway devices. There is a unique relationship between flow rate and upstream water level when the flow is able to discharge freely over the weir (ie under modular conditions) but not once the downstream water level is influencing the upstream level (ie during drowned flow conditions). Discharge equations for specific weir characteristics can be determined by reference to relevant hydraulic textbooks (eg Chow, 1959).

courtesy Roger Nowell

courtesy Robert Bray Associates

courtesy Robert Bray Associates

Figure 28.20 Examples of outlet control weir structures

Weirs can be set into embankments, forming a point of visual interest, in which case full consideration should be given to the use of natural construction materials. If they have to be housed within subsurface chambers, special consideration should be given to their long-term operation and maintenance to ensure robust consistent performance.

28.5.6 Exceedance flow outlets

A specific overflow system may be required to manage exceedance flows for:

- conveying flows of a greater severity than those handled by the overflow weir incorporated in the outlet structure
- preventing over-topping (and potentially catastrophic erosion) of any perimeter embankments, caused by blockage or other failure of the outlet structure.

In the case of ponds and detention basins that come within the ambit of the Reservoirs Act 1975 as amended by the Flood and Water Management Act 2010 (ie facilities with > 10,000 m^3 of stored water), there is recognised guidance on the appropriate exceedance probability for the design flood to be passed via the emergency spillway (ICE, 1996). This guidance is also relevant for ponds and detention basins that are not covered by the Act, but would nevertheless represent a significant hazard if the embankment were to fail due to flood over-topping.

The exceedance flow route for ponds and detention basins normally comprises an open weir and channel, the reasons for this being that:

- the discharge rises non-linearly, resulting in significant increases in flow for small increases in head
- there is a low risk of spillway blockage by debris or by incorrect operation.

Other alternatives may be acceptable – for example a labyrinth weir, a siphon, or a bell-mouth spillway discharging to a closed conduit – but spillways using gates or other moving parts are unlikely to be appropriate. The design of grass-lined spillways has been documented in Hewlett *et al* (1987).

28.5.7 Passive devices (vortex flow controls)

A number of devices are available that can vary the hydraulic characteristics of the simple orifice.

Vortex flow control devices tend to have an "S-shaped" discharge curve (**Figure 28.21**), built up of three distinct phases, each corresponding to a different governing flow control regime:

1. **Pre-initiation phase** – at low heads, the inlet and outlet openings of the device are not submerged, and the openings therefore act in a similar manner to an unsubmerged orifice plate. The end of this phase is often characterised as the flush-flow or flushing point (note that this does not mean that the devices are self-flushing).
2. **Transition phase** – as the head increases, the inlet and outlet openings become submerged, and a vortex will begin to form. In this region, the flow regime will be turbulent and unstable, as the vortex will continually form and collapse, and there is insufficient energy within the flow to form and maintain a stable vortex. A volume of air will generally become trapped inside the device, above the inlet and outlet openings, although some devices incorporate ventilation holes in the unit to prevent or inhibit this. This air pocket will initially compress, but will then start to exert a counter-pressure against the flow of water and cause the flow rate to decrease as the head increases. The end of this phase is often characterised as the kick-flow, kickback flow or switch point.
3. **Post-initiation phase** – as the head level continues to increase, the entire unit becomes submerged and sufficient hydrostatic pressure is generated to displace the air pocket and allow a stable vortex to form with a central air-filled core. This air-filled core acts as a pseudo-physical restriction by reducing the cross-sectional area of the device available for the passage of water. In this region, the device will operate in a similar manner to a submerged orifice plate (**Equation 28.1**), with A_o being the area of the outlet of the device minus the cross-sectional area of the air core.

As the water level subsides following the rainfall event, the level within the control structure will eventually fall below the top of the device and due to dropping pressure, the vortex will collapse. The collapse in the vortex produces a sudden increase in the flow through the device.

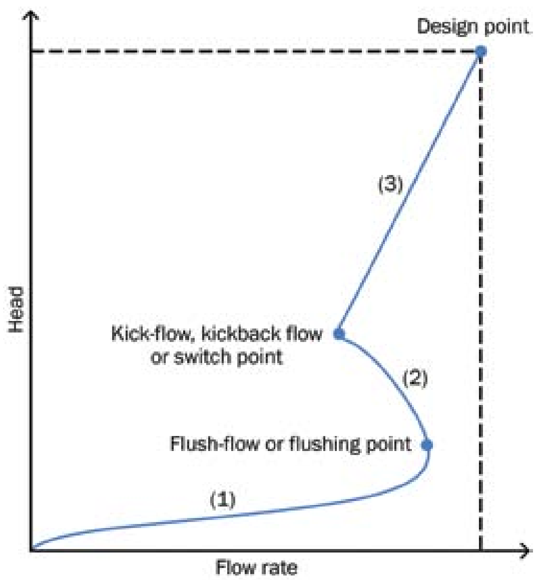

Figure 28.21 Example of head–discharge relationship for passive devices (vortex flow controls) (courtesy Hydro International)

Much like an orifice, when the device is discharging as a free outfall, then the effective head is measured from the upstream (headwater) surface level to the level of the control (generally taken as either the centreline of the outlet or the invert level of the outlet). If the outlet of the device is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces (**Figure 28.16**).

Compared to the steady increase in flow with head as provided by an orifice plate control, the S-shaped head-discharge curve has:

1. increased pass forward flows during the early stages of the build-up of upstream head. This feature of the curve can sometimes enable better use of the available downstream capacity and reduce upstream attenuation requirements. This effect is marginal for very shallow storage systems and in any event any saving in storage should be assessed against the cost of the vortex control
2. a limited variation in flow across a range of heads. This feature of the curve can sometimes be advantageous where the control structure aims to deliver a particular target flow rate to a downstream component or infrastructure. The flow rate can often be within ±5% of the target value over a wide range of operating heads (**Figure 28.22**)
3. a comparable head–discharge relationship to a simple orifice plate once the design point has been reached.

There are a number of configurations available for passive (vortex) type devices, all of which rely on the same basic processes described above. It is worth noting, however, that the shape of the curve will often vary between different configurations (**Figure 28.23**), which can have an influence on pass-forward flows and attenuation volumes when dynamic hydraulic modelling is undertaken.

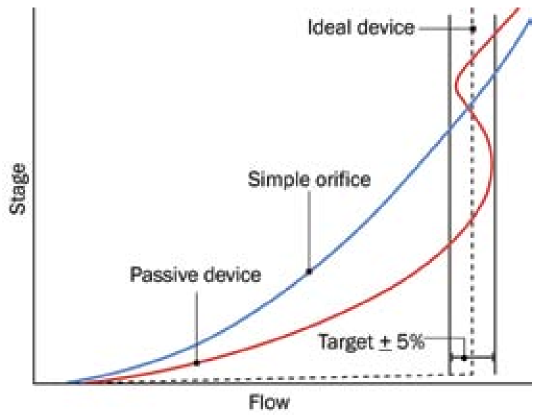

Figure 28.22 Comparison of hydraulic performance for various devices (from EA Fluvial Design Guide)

As systems can differ, it is important that evidence is provided to support quoted performance. There are no known standardised test methods and reporting protocols for passive flow control devices. However, it is recommended that testing is undertaken by organisations that are independent of the manufacturer, in order to ensure that the quoted performance is supported by robust evidence using appropriate test methods. Alternatively, the testing and results should be peer reviewed by an independent third party.

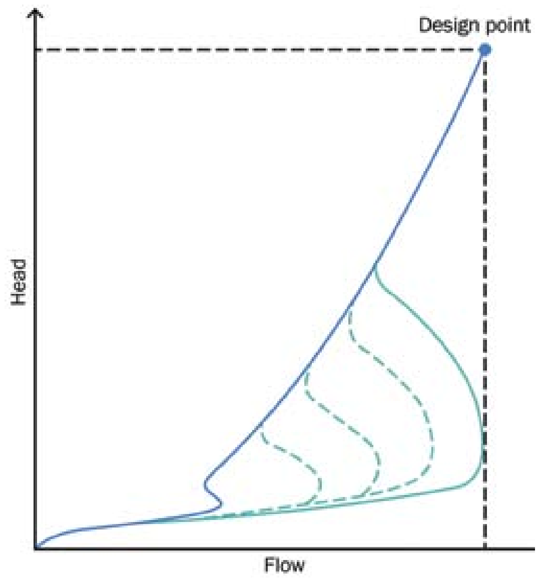

Figure 28.23 Examples of varying hydraulic performance for passive (vortex) type devices (courtesy Hydro International)

Devices are generally configured either with a submerged inlet and “snail” shape to develop the swirl required to form the vortex or with level inverts and a conical shape to develop the swirl. Devices can be used for above or below ground systems.

Features of passive (vortex) devices include:

- a larger cross-sectional area than that of a comparable orifice that is sized for the same design point, reducing the risk of blockage (although orifice plates can be designed to minimise the risk of blockage to the same level by using screens)
- a larger cross-sectional area than that of a comparable orifice that is sized for the same

design point and no vena contracta effect, thereby reducing exit velocities and risk of scour of the downstream channel (although in a well-designed SuDS scheme, flows should be low enough that scour should not be a problem)

- energy dissipation within the vortex, reducing the need for separate energy dissipation structures (although in a well-designed scheme flows should be low and should not need large energy dissipation structures).

Figure 28.24 Example of a “snail” type device (courtesy Hydro International)

Figure 28.25 Example of a conical type device (courtesy Hydro International)

The design of passive (vortex) type devices is generally undertaken by manufacturers to suit the particular application. Some manufacturers provide a range of standard, off-the-shelf configurations allowing the designer to pick the device most appropriate to their needs. Off-the-shelf devices are lower cost than bespoke devices. Characteristics of different devices are also included in commercially available hydraulic modelling software packages.

Multiple devices can be used in series, in parallel or in combination with other controls, such as orifices or weirs to meet the requirements of different return periods.

Figure 28.26 Two passive devices for multiple flow control (courtesy Hydro International)

28.5.8 Active devices

Active control systems provide the operator with the ability to take an operational action based on the current or predicted status of the system at one or more locations. This requires the status of the system to be measured at key points, and the information has to be relayed to a control unit or operator (eg where pumps are switched on based on a water level status). The action can be a manual or automated intervention.

SuDS, as with any other form of drainage, can potentially benefit from decisions to control flow rates in various parts of the system at particular times. The critical duration event for most SuDS components is quite long, and for the main attenuation storage it is often longer than 24 hours. In comparison, receiving sewers may have critical durations in the range of 30 minutes to 2 hours. This provides an opportunity for active controls to prevent runoff from the site during periods when the sewer is already at capacity.

Active controls are not normally used to deliver the standard hydraulic criteria associated with discharges from sites, though sensors could be used to measure flows in the system and control flow rates accordingly using variable throttles, provided that the return period of the event taking place could be pre-established.

The performance of active control units can be designed to meet the flow requirements for a range of return periods with a single device thus avoiding multiple units.

Float or displacement control systems generally make use of adjustable gates attached to a float or counterbalance. Rising water levels will cause the float to rise or will exert greater force against the counterbalance to progressively reduce the cross-sectional area of the outlet opening. There can be problems with debris or ice affecting the movement of the gate, and maintenance regimes will need to be robust to ensure the continued operation of the control device.

Active systems that operate in real time will need to incorporate sophisticated control and feedback systems that detect water levels within the drainage system and adjust the flow control settings accordingly. This type of system allows the flow characteristics to be close to ideally matched to the site requirements and can often be programmed to meet the requirements of a range of conditions, but will include significant additional costs for both installation and operation and maintenance. Also, there is a need to make sure that there is a failsafe state that operates if power failure or other problem occurs.

Pumps can be used on SuDS where required, but in most cases it is better to keep water at or close to the surface and use gravity flow systems wherever possible to minimise energy use and to reduce the risks associated with power failure.

28.5.9 Energy dissipation

The primary objective of erosion protection at pipe outlets is the reduction of velocity. Therefore, a key consideration in selecting the type of outlet protection is the design outlet velocity for the pipes or channels involved. This will be dependent on the flow profile associated with the design storm. Where flows have been effectively managed at source, energy dissipation structures should usually only be required for overflows and emergency spillway structures.

Examples of energy dissipation options include:

- reducing outlet velocities using upstream SuDS component and/or flow controls
- reducing pipe gradient (but not less than the required self-cleansing velocity)
- rip-rap aprons and basins
- loose stone
- gabions
- reinforced grass
- granite setts
- concrete stilling basins
- baffle blocks within a headwall.

For SuDS designs, hard systems such as concrete stilling basins and baffle blocks should not be required as velocities should be relatively low. Flow alignment and outfall setback can be considered in conjunction with energy dissipation in sensitive receiving environments.

A few of the options are described in more detail in the sections below. Further guidance (including detailed design equations) is available in HA (2004), Balkham *et al* (2010) and Kirby *et al* (2015).

Rip-rap aprons

A rip-rap lining is a flexible stone layer. It will adjust to settlement, can also serve to trap sediment and reduce flow velocities through a higher Manning's roughness coefficient. The velocities from SuDS components should be sufficiently low that protection such as aprons is rarely needed. Where piped flows produce erosive conditions that cannot be avoided appropriate hard engineering designs need to be developed using standard guidelines and manufacturer's design guidance.

Gabions

Gabions can be used as an erosion dissipating surface beneath an outfall. The boxes should either be manufactured of stainless steel or of galvanised steel wire with a PVC coating to prevent zinc from entering the water. The rock or gravel fill should be of a sufficient diameter to prevent washout (usually single sized stone) and the dimensions of the blanket should follow a similar design process to that given in **Equation 28.1**.

Gabions in SuDS are usually not load-bearing and therefore thin mattress types (150 mm or so) are usually sufficient. These also allow vegetation to become established, which acts to aid their function in the system.

28.5.10 Outlet protection

If not adequately protected, small, low flow orifices can easily block, preventing the structural control from meeting its design purpose and potentially causing flooding and other adverse impacts. There are a number of different anti-clogging design approaches, including:

- gravel surround
- gabion protection
- reverse slope outlet pipe for a pond or wetland with a permanent pool; the submerged inlet prevents floatables from clogging the pipe, and this also avoids discharging warmer water at the surface of the pond, but this design option is not easily visible and therefore its maintenance tends to get overlooked, increased long-term blockage risks
- orifices protected within perforated risers or T-pieces
- debris guards (stainless steel guard open top and bottom)
- “hooded” outlets

Examples of debris guards are shown in **Figure 28.27**.

Figure 28.27 Examples of debris guards over low-flow outlet control structures (courtesy Robert Bray Associates)

28.5.11 Trash screens and safety grilles

Balkham *et al* (2010) and Graham *et al* (2009) contain guidance on the use and design of screens (trash screens and security grilles), appropriate to UK conditions.

The reasons for providing a screen are to:

- exclude trash which might otherwise block the conduit
- capture debris in such a way that relatively easy removal is possible
- prevent unauthorised access, particularly by children and small mammals (eg dogs).

Trash screens and security grilles require regular maintenance and in general do not reflect SuDS best practice. It is recommended that such systems are only used in exceptional circumstances.

Inlet Outlet

Figure 28.28 Examples of trash screens (courtesy Illman Young)

Screens can often be the cause of significant problems, and their susceptibility to clogging should always be given full consideration. First, the trapped debris may accumulate and result in severe impairment of the discharge capacity of the conduit. Second, the use of security grilles on the outlet from a pipe or culvert can result in debris accumulation that is difficult to remove. Balkham *et al* (2010) therefore recommends that a thorough assessment be carried out of the need for screens and that, wherever possible, screens should be avoided.

In cases where there is easy public access and an outlet structure discharges to a pipe or culvert that would be hazardous to enter, or where there is a supply of vegetation and other debris that is liable to block a flow control device (such as a small orifice), the structure should be protected for example within a gabion, or else an entrance screen may be required. The screen aperture should be chosen to exclude debris liable to cause a problem, but allow through smaller debris that is unlikely to cause a blockage. Consideration should also be given to whether or not a grille could be classed as a foot trap/trip hazard, such as 50–75 mm mesh sizes where the mesh could be walked over by children.

If it is decided that the exit from a pipe or culvert should be screened for security and/or safety reasons, it is important that a significantly finer screen be deployed at the corresponding entrance, so as to avoid the passage of debris of a size liable to cause blockage of the exit screen.

Trash screens should be large enough that partial plugging will not adversely restrict flows reaching the control outlet. A commonly used rule thumb is to make the screen area more than 10 times larger than the control outlet orifice. The surface area of the screen should be maximised, and the screen should be located a suitable distance from the protected outlet to avoid interference with the hydraulic capacity of the outlet. The spacing of the bars should be proportional to the size of the smallest outlet protected, but separate screens can be used for different sized outlets. The screen should normally have hinged connections to facilitate the removal of accumulated material, except where fears of vandalism require a fixed grille approach.

Minimising health and safety and operational risks should be key concerns. Any grille should be able to be cleared during events from a safe location. Structural design considerations are set out in **Box 28.1**.

BOX 28.1 Structural trash screen design criteria

1 Confirm need

Only provide a trash screen where there is a high risk of blockage, and where such a blockage would be significant. Major indicators are a bend or obstruction in the culvert, a very long culvert with difficult access or a debris load that potentially contains large items.

2 Estimate debris amounts

Debris is either high (more than 60 m^3 per year), medium (30–60 m^3 per year) or low (less than 30 m^3 per year). Leaves, twigs and small branches will rapidly block a screen, with blockages usually being formed by one or two large items supporting smaller debris.

3 Design of screen

Screen angle should be 60° or less to the horizontal.

Bar spacing should not exceed 150 mm, if designed as a security screen, and should not be below 75 mm to avoid trapping small debris.

Height of the screen should not exceed 2 m.

Gross area of screen should not be less than the following:

Debris loading	*Screen gross area*
< 30 m^3/year	the greater of 6 m^2 or 3 × culvert area
30–60 m^3/year	the greater of 9 m^2 or 7 × culvert area
> 60 m^3/year	the greater of 12 m^2 or 9 × culvert area

Steel member sizes should not generally be less than 75 mm by 8 mm flats (25 mm for round bars), with lengths over 1.5 m braced.

28.6 FLOW MEASUREMENT

If accurate flow control is required, perhaps also with the facility for monitoring flows during floods, then further steps need to be taken in the design, to ensure that appropriate forms of flow control device are used, and that the conditions are suitable for that purpose. This would require the use of upstream level measurements together with components such as:

- thin-plate orifice
- thin-plate weir (rectangular and V-notch)
- Crump weir
- critical-depth flume.

These require routine attention to maintain their performance, but this is normally no more than:

- removing any accumulations of sediment that may affect the hydraulic behaviour
- brushing the surfaces to remove slime and algae.

Thin-plate orifices and weirs can sometimes develop leakage problems and also require occasional renewal or refurbishment if their performance is starting to be affected by a loss of true edges, compliant with the requisite standards.

▶ Further information on flow measurement structures is given by Ackers *et al* (1978), Bos (1989) and in the relevant British Standards.

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STATUTES

Acts

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Reservoirs Act 1975 (c.23)

Image courtesy Illman Young

29 LANDSCAPE

Contents

Chapter 29 Landscape

This chapter discusses landscape within the context of SuDS design and its overarching design principles.

▶ *Chapter 10 provides further discussion related to the design of SuDS in an urban context.*

▶ *Chapters 11–23 provide guidance on the engineering and technical design issues related to landscape and planting for different types of SuDS component.*

29.1 INTRODUCTION

The term “landscape” encompasses the entirety of all external space, whether urban or rural. Considering the character and qualities of the existing landscape, and the way in which new elements or development are assimilated within this greater landscape allows them to be designed appropriately from concept to detail.

The design of the landscape element of SuDS is a critical part of its delivery, both in functional and aesthetic terms. Depending on the scale and location of a site, hard or soft landscape elements may comprise almost the totality of the drainage system, provide a range of specific components, or may be limited to just one or two particular uses. Regardless of this, the same attention to detail is required in designing both the hard and soft landscape as is required of the engineering.

To achieve the optimum result that allows landform, hard materials and soft landscape to play their roles in delivering the Management Train, and particularly the amenity and biodiversity elements, the landscape architect should have a fully integrated role within the design team. Where a scheme is predominantly a “soft” planted system, the landscape architect or landscape manager, may play the leading role.

However, this should be determined on a project-by-project basis, the most important factors being the need for effective communications within the design team and a shared vision over the design and its delivery. This will help ensure that multi-functional benefits can be achieved, because integrated design is most effective when it is an inherent part of the site master planning process (**Chapter 7**). For example, the production of a planting and management plan for an unsympathetically engineered balancing pond does not fulfil the ethos of integrated SuDS or its design criteria.

Design of the landscape should include:

- assessment of the value of existing trees or habitats for retention, and their protection throughout the project
- consideration of landscape/townscape character, both of the site itself and its broader setting
- understanding the requirements of the users in terms of access, circulation and their intended use of the site
- appropriate responses to the site constraints and opportunities, including slopes and gradients, soils and aspect, and how levels relate to the buildings and the intended use of the open areas
- review of a range of potential solutions and the way that hard and soft solutions can be effectively integrated to meet the site’s requirements

- agreement over the extent of land needed for soft elements
- agreeing capital and maintenance costs
- addressing health and safety factors, and maintenance requirements.

Landscape architecture or design encompasses both the hard and soft elements of the natural and built environment. These should be designed together, if they are to work most effectively and to achieve a visually harmonious result. The SuDS should therefore be integrated within the greater landscape concept in its entirety, so that the range of hard landscape and paving materials (their functional properties, scale, colour, texture and use) is used consistently around the site, in a way that is complementary to those used for any buildings on the site. Elements that may be specific to the SuDS, such as railings, fencing, headwalls and signage, should similarly be considered as an integral part of the overall design palette.

29.1.1 Objectives for a landscape scheme

A comprehensive SuDS landscape plan should therefore consider the extent to which it can achieve the following objectives:

1 Design for effective attenuation, flow control and exceedance

A wide range of soft landscape features can be used to provide space for infiltration or attenuation storage.

While flow control measures will usually require hard structures (**Chapter 28**), where these are above ground, they should be designed in an attractive manner as part of the overall landscape, using locally appropriate materials. However, ground form can also be used, and densely vegetated surfaces on shallow gradients can significantly slow flows through their hydraulic roughness.

All schemes should consider exceedance flows, and these can often be channelled through soft landscape areas (ideally grassland) via shallow and subtle ground modelling.

2 Improve water quality

A wide range of water quality improvements can be achieved by using vegetated surfaces as part of the Management Train (**Chapter 26**). Grass is particularly effective at dealing with sediments and pollution where sheet flow is used, and planted components that dry out between each rainfall event are an efficient means of promoting bioremediation. However, planting and grassland generally can be used to provide a wide range of water quality improvements by providing good erosion protection to banksides and slopes, optimising silt interception and minimising resuspension, and providing a bioremediation substrate for the treatment of pollution.

3 Provide an attractive new feature in the local landscape

The aesthetic appeal of a SuDS component or scheme is an important part of its public and social acceptability (**Chapters 5 and 10**). This can be achieved using carefully considered ground contouring, planting and the design of both the hard landscape and open water features. The overall layout, planting and ground modelling can be used to create or restrict views of attractive features, both within and external to the site or to screen unsightly elements.

An understanding of the local urban/landscape character, and both its positive attributes and detractors, should also inform the design process to ensure that the new feature is locally appropriate.

4 Improve ecological function and biodiversity

SuDS introduces the opportunity for adding or enhancing wetland habitat (**Chapter 6**), which can increase a site's biodiversity potential, particularly where habitat creation includes new features such as damp wetland or permanently wet areas already. Enhancing biodiversity requires that a variety of habitats are provided within a site, incorporating new, ecologically appropriate features.

Wherever natural habitats of value exist, these should be preserved and should only be incorporated within SuDS schemes where there are no risks to their ecological status, and they are compatible with the SuDS and a clear benefit will be achieved.

It is essential that the right soil and ground conditions are provided related to the habitats to be created, and that the establishment and maintenance specification for the planting recognises any specific requirements (particularly seasonality) or horticultural operations for doing so.

5 Use land efficiently and enhance land values

The use of soft landscaped SuDS within a site can allow the efficient use of land by providing multi-functional uses, where, for example, permanent ponds with a storage function can become attractive and biodiverse landscape features (**Chapters 5 and 10**).

Provided that the design and scale of these SuDS components fit appropriately within an area of public open space (POS), they can form part of the general POS requirement. However, visually dominating or fenced engineered ponds are unlikely to form part of a POS requirement; indeed, they may be unacceptable to the local authority and will not provide multi-functional landscapes.

Small-scale SuDS components, such as rain gardens, can be incorporated within gardens, and provide both Interception and attenuation to at least the 1:1 year requirement, and potentially to 1:30 years or more, thereby reducing the storage requirement further down the system.

Sites with good quality landscape schemes are known to enhance public health and wellbeing, as well as increasing land values and improving their saleability, with housing developers reporting that properties facing onto SuDS sell quicker and/or for higher values than the same properties elsewhere. Conversely, poor landscape can contribute to a poorer quality of life for residents, and contribute towards the value of the site falling.

All landscape should have a clear, effective and practical design and management plan to allow the benefits to be maintained in the long term.

6 Assess risk and reflect the response within the design

The risk inherent in open water features should be assessed for each site individually (**Chapter 36**) and the appropriate measures incorporated within the design.

Simple design principles around good sightlines into water areas, shallow gradients at the water line and defensive planting can contribute much towards reducing risk.

Maintenance operations should also be considered to ensure that any machinery necessary for both routine and periodic maintenance is able to access the SuDS easily and safely.

29.2 LANDSCAPE CHARACTER

Landscape character identifies and describes the specific character of each landscape, that is the unique combination and pattern of elements and features that makes each distinctive to its local area and different from others.

Landscape character areas have been mapped at a regional, district and local scale, along with seascapes, the description of which also shows how the landscape is perceived, experienced and valued by people. National Character Areas (Natural England, 2012) can be downloaded from their website. County or local character assessments are available on-line from local planning authorities.

Understanding what makes a landscape locally distinctive should be a fundamental part of determining new interventions or designing within it; for new development it may have been the subject of a landscape and visual impact assessment. The character and visual quality of SuDS in rural and semi-rural landscapes should be carefully considered, as poorly conceived designs can form alien or unnatural features, out of character with the local landscape. This can be particularly true of ground modelling, where modelling is viewed against the skyline, or where the local topography is naturally steep or shallow. Similarly, planting will require careful consideration.

The rationale for how and why the SuDS landscape design has been developed, and the way it responds to landscape character, should form a key part of the design and access statement accompanying any planning application, and should support the way that these principles have been applied to the landscape more generally.

29.2.1 Urban and suburban considerations

While landscape character descriptions apply to the wider landscape rather than urban areas, the principle of understanding the local vernacular, its character and the historic, cultural and social influences on an area, should influence design wherever it is located.

Information on townscape character can be found within local authority documents, such as townscape assessments, conservation area statements, village design statements or development briefs for individual sites.

Understanding the vernacular, particularly in relation to hard materials, their methods of use and locally typical planting should form an important design consideration. This does not undermine the designer's desire to create something modern or in contrast to the local vernacular, but it should be informed by a thorough understanding and appreciation of it. In many instances, creating a positive design statement that is well informed by local influences can contribute to enhancing local distinctiveness and identity (see also **Chapter 10**).

29.3 SITE CONSIDERATIONS

Achieving an attractive and functional soft SuDS scheme is dependent on fully understanding the site's character: the conditions of slope, gradient, ground modelling, geology and soils, and natural drainage patterns alongside the value of retaining existing natural site features such as trees, hedgerows or areas of important habitat. The character of the site itself should also be considered in the context of the surrounding land uses or landscape.

Preliminary understanding the characteristics of the site should be undertaken at the conceptual design stage, as described in **Section 7.6.1**. More detailed assessment and design approaches will be undertaken as the design progresses through outline and/or detailed design (**Sections 7.7 and 7.8**).

29.3.1 Existing natural features on site

Existing natural features on site may include trees or hedgerows, or habitats of ecological value. Where the site will be subject to development, and such features potentially affected, they should be subject to the appropriate survey, which should inform the design and development process. Initial checks should be made with the local planning authority to ascertain whether such features are already covered by protective designations:

- **trees** – by either individual or group tree preservation orders (TPO), or automatically by virtue of their being located within a conservation area
- **hedgerows** – may come within the scope of The Hedgerow Regulations 1997
- **habitats** – the site may be designated as a site of special scientific interest (SSSI), site of importance for nature conservation (SINC), local nature reserve or may contain protected species.

Existing trees on site should be subject to a pre-development tree survey in accordance with BS 5837:2012, and this should be undertaken by a "competent" person, as defined by the standard. The outcome of the survey should be recorded on an accurate topographic survey with accompanying schedules, recording all the trees or tree groups, their species, height, spread, girth, current condition, likely useful life expectancy and an assessment of their value for retention from A to C. Trees in very poor condition are classified as U, and consideration should be given to measures for their removal or for them to be made safe. The survey also establishes the root protection area for each tree, which should not be damaged by excavation or building works without prior agreement. All grade A trees should be retained, as many grade B as possible and grade C trees if so desired.

Existing hedgerows should be surveyed for their continuity, quality and species mix, and graded in line with guidance from Defra (2007).

Existing habitats should be subject to a phase 1 habitat survey. Where protected species are either present or assessed as being likely to be present, then further detailed species-based surveys should be undertaken to inform the location of any development works and necessary mitigation measures. Such works may be subject to a licence from Natural England. Surveys can only be undertaken at the appropriate time of year, and the timings vary depending on the species involved.

All features to be retained should have appropriate protective fencing (or other measures) as per the relevant guidelines, put in place before any works commences, and should be retained intact for the duration of the works or as specified in any licence. Some works may also be restricted during certain months of the year to prevent undue disturbance to wildlife.

29.3.2 Gradients and ground modelling

Successfully integrating SuDS invariably requires areas of ground modelling to accommodate swales, bioretention areas, detention basins, or larger permanent wetlands, ponds and lakes as well as general regrading for the built development. On development sites excess fill may also need to be reprofiled within areas of public open space adjacent to the SuDS to balance the overall cut and fill operation.

Integration of the proposed landform, therefore, requires the ground form beyond the SuDS component to be considered, and its contouring adjusted to allow the levels to flow around and into it, in a naturalistic manner that is visually attractive, and accords with the local surrounding landscape. Features should be located to fit within the landscape and its natural contours, noting that the largest features will invariably be found towards the downstream end of the site.

Slopes at constant gradients tend to look over-engineered and unnatural, when used in naturalistically designed schemes, unless such slopes are locally typical. Therefore, consideration should be given to where these can be made more variable, without undermining the performance or safety of the SuDS component.

Overly steep slopes may create adverse impacts on the character of the landscape or visually, if the features are of sufficient size or create a notably alien feature. Slopes steeper than 1 in 3 may require stabilisation through bioengineering (or other means), dependent on the height and the strength of the superficial geology. In such cases, advice should be sought from an engineering geologist or geotechnical engineer. Ideally a range of gradients should be used that reflect the natural landform outside the feature, while internally they should be used not only to create variety to the banks, but also to develop areas around the base and its edges that will encourage a more diverse range of species. Wetland and aquatic plants naturally colonise in a relative narrow range of (normal) water levels, so that even slight variations in level will encourage greater plant diversity.

Banks on the "downward" side of ponds, where water is being held above natural ground levels should be avoided where possible and can be the most difficult to assimilate successfully, so that these slopes may require extensive planting to help mask their inherently unnatural qualities. The top and toe of slopes also require extra space to allow a more gentle transition between the slope and the adjacent ground.

Gradients around permanent water bodies should respect health and safety requirements for shallow slopes at the water line and safety benches (see **Chapter 36**). Changes to landform should also respect the protected root protection zones of trees to be retained as defined in the tree protection plan, and set-off distances of (ideally) 4 m to the centreline of retained hedgerows. Maintenance requirements for access should also be considered.

29.3.3 Soils

Natural soil is a precious, expensive and limited resource, and should be treated with the necessary care to enable it to be stored and reused on site in good condition. Defra (2009) deals with the assessment, handling and management of soils, but generally the following key issues should be addressed:

- Unwanted existing vegetation on areas to be stripped and stored should be cut down and/or sprayed out with contact herbicide before stripping.
- Topsoil and subsoil should be stripped and stored separately and should not be compacted.
- Wet soils should be stockpiled no higher than 2 m, and ideally 1.5 m, in linear rows with the top and sides profiled to shed water (Defra, 2009).
- Dry soils can be stockpiled higher and the stockpile surface should be compacted to seal it from wet weather (Defra, 2009).
- Stockpiles should be sown with a clover mix if they are to be left for more than six months before use, or any weeds that grow should be regularly sprayed with herbicide to prevent the build-up of weed seeds.
- Stockpiles should be protected from contamination by rubbish, rubble or building operations, particularly chemicals or leachate from site works.
- Soil should only be stripped, stored or spread in appropriate weather conditions, and operations ceased if the ground is waterlogged, or during periods of heavy rain.

Before spreading subsoil or topsoil, the ground should be prepared by clearing any existing weeds (if spreading subsoil, then strip any topsoil first), and ripping through the soil to allow good cohesion between the existing and new soil. Soil should be spread in layers no greater than 300 mm depth (HA, 1981 and Defra, 2009) and lightly consolidated, not compacted. A degree of natural settlement should be anticipated when setting finished levels, so tolerances in specified levels should reflect this.

29.3.4 Contaminated soils

While contaminated land is dealt with in **Chapter 8**, contamination should be considered in terms of its potential impact on both humans and plants. Some contaminants will radically affect the development of plants, but may be sufficiently remediated by soil treatment and/or the use of fertilisers and organic composts. Alternatively, a capping layer incorporating a layer of clean soil (and possibly a geomembrane) may be required between the contaminated ground and plants, to prevent uptake of the contaminants. However, this is a specialist area, and detailed and comprehensive soil sampling will be required. Advice should be sought from a soil or landscape scientist, with expertise in plant establishment as well as contaminated land professionals.

29.3.5 Compaction and soil condition

Before undertaking any groundworks on site, all trees to be retained should have their protective fencing erected at the recommended distance as determined in the tree protection drawing (as defined in BS 5837:2012), to avoid damage to either the tree's canopy or root system (**Section 29.3.1**).

Soil compaction is very common on development sites (**Chapter 31**), and can inhibit or even prevent plant growth and reduce the soil's ability to infiltrate and percolate water. Heavy machinery can create solid pans or glazed surfaces between soil layers, which act as impermeable barriers to both water and root growth. Soil surfaces should, therefore, be ripped (with a three-tine subsoiler or chisel plough if space allows (**Figure 29.1**), in transverse directions, or thoroughly loosened with an excavator fitted with a ripper tine attachment on small sites) before the spreading of subsoil and/or topsoil, and the whole soil profile re-ripped on completion before final cultivations. The depth and route of any underground utilities should be taken into account during these operations.

Three-tine subsoiler | Ripper tine attachment | Chisel plough ("Shakerator")

Figure 29.1 Examples of soil conditioning equipment (courtesy Tim O'Hare Associates)

29.3.6 Utilities and other site infrastructure

The location of existing utilities and other site infrastructure should be considered when designing SuDS, and the location of any new services co-ordinated to avoid potential conflict with the proposed SuDS.

Piped water from a SuDS component should run below any existing services, and any "at ground level" features, such as a pond or swale, are unlikely to be permitted above services, so this will require discussion and approval from utility companies.

Existing underground services are particularly challenging in retrofit projects. Asset databases of buried infrastructure should not be considered as definitive and should be checked with surveys.

29.4 BIOENGINEERING

The use of bioengineering techniques and a wide range of soil reinforcement treatments on the banks of watercourses can be useful to help deliver effective SuDS. They can be particularly effective for bank stabilisation adjacent to watercourses subject to occasional high or fast flows, or soil retention on steep slopes, although these should be avoided if located immediately adjacent to a proposed SuDS or water body (**Chapter 36**). Steeper gradients may, therefore, be required as part of an overall SuDS to allow shallower gradients by the water's edge.

Bioengineering allows the integration of soft landscape with the durability benefits provided through below-ground engineering to help achieve and maintain watercourse formations in their designed form. Solutions can include geotextiles, cellular confinement systems and vegetated barrier structures, which can achieve a far softer and natural solution than hard landscaping features, such as sheet piling or concrete banks. Gabions can also be considered, although the effect will not be of a completely soft system.

29.4.1 Developing technology

Products in this area are continuing to develop, so an on-line review of potential products and applications is advisable. At present, the range of soil retention solutions varies from natural materials, such as coir fibre, faggots and rocks, to manmade materials. The choice of material used will be site specific and dependent on its application, whether the system is necessary to aid establishment of the SuDS or whether it is required as part of its long-term durability and performance, with materials to aid establishment generally tending to be biodegradable.

Generally, natural materials are likely to be most suitable for shallower banks and lower water flows, accommodating stability for initial plant establishment to stabilise the banks themselves. Where banks are steeper or are subject to higher flows or greater velocity, durable manmade products may be better suited to providing more permanent stability.

29.4.2 Soil reinforcement

Different levels of reinforcement are needed, dependent on the steepness of slope, likelihood of exposure to water erosion and type of vegetative establishment desired. Typical products are shown in **Figure 29.2**.

Cellular confinement systems consist of a flexible material forming honeycomb or diamond-shaped cells, laid and fixed onto the bank, filled with soil and planted or covered with grass, and are also available in larger forms, used as "blocks" to create a river bank. The cellular formation provides extra strength to the top layer of soil and prevents it sliding downhill, making it suitable for use on steeper slopes (up to 1 in 1), although much shallower slopes are recommended for use in SuDS. Due to the mesh sizes, only young small plants can be used if a planted bank is desired.

Turf reinforcement mat is a strong mat of fibre layers fixed onto slopes to be seeded or planted into, offering further stability for plant establishment. This initially and permanently strengthens the bank, which is then reinforced as the plants or grass establishes (up to 1 in 3 slopes). Preseeded mats are also available.

Reinforced turf is pre-grown with an incorporated fibre mat to be unrolled and fixed onto slopes, which provides an immediate result and is supplied in large rolls, which inherently provide a good initial degree of durability.


Cellular confinement (courtesy TERRAM)


Reinforced mat for grass/planting (courtesy Salix Bioengineering)


Reinforced turf (courtesy Salix Bioengineering

Figure 29.2 Bioengineered slope stabilisation options

29.4.3 Bank stability and erosion

Various products are available for use on banks to help stabilise soil structures, encouraging better vegetative growth and this further improves bank stability and prevents erosion. While they are generally used in larger river restoration projects, they are also likely to be useful at outfalls from SuDS to an adjoining watercourse, or in retrofitting schemes where space is limited but a soft solution is desired. Discussion of typical products is provided in **Section 30.5.7**.

Coir rolls and pallets/mattresses help to prevent bank erosion, allow settling of sediment and facilitate the stabilisation of banks through plant establishment. They are available with pre-established vegetation or can be planted *in situ*.

Rock rolls prevent bank erosion, by acting as a crash barrier in front of the less stable natural soils behind. Vegetation can establish within the rolls, aided by sedimentation. They are often used as a first line of defence, in front of coir rolls, to avoid erosion by abrasion, providing greater longevity to the coir rolls and a better environment within which the vegetation can establish.

Rock mattresses are often used to create new stream or river bases, giving a hard-engineered stability with less detriment to the riverbank appearance. A range of rock or stone can be used to improve visual quality, and where sedimentation occurs, planting can naturally establish over time. Consideration should be given to ensuring that rock or stone is used that is typical of the local area, although it should also be sufficiently durable for its proposed use. Rock mattresses and gabions can also be used on banks, to offer protection from erosion, especially on the outer side of meanders, while also assisting with plant establishment in faster flowing areas. These require careful design to ensure their successful visual integration within the overall SuDS, although they are only likely to be required on very large schemes with high flows.

Live willow revetments are generally used to edge or restore river banks, or to terrace them, so they are only likely to be used for large-scale features. Once they are installed, the ground behind is backfilled and can be planted, preventing erosion of the banks. While this approach is better for biodiversity, it may not be suitable in areas of high velocity water flows. The site should also be suitable to accommodate willow trees, both physically and visually, once they establish, and those managing the site, should be clear about the maintenance and management that will be required.

Coir rolls

Coir mattresses

Rock rolls

Rock mattresses

Willow revetments

Figure 29.3 Bioengineered bank reinforcement options (courtesy Salix Bioengineering)

29.5 TOPSOILS, AMELIORANTS AND MULCHES

The use and management of natural soils, or the potential use of "manufactured" soils as natural soil becomes an increasingly scarce resource, should be considered. Soils are essential for good drainage and should also provide the necessary nutrients for healthy plant growth to achieve rapid establishment and ground cover desired for its function as part of the SuDS. This section principally relates to topsoils; engineered soil (which can be used instead of topsoil) is covered in **Chapter 30**.

29.5.1 British Standards

BS 3882:2015 specifies requirements for topsoils that are moved or traded. It is not intended (or appropriate) for the grading, classification or standardisation of *in situ* topsoil or subsoil that is already present on site. The standard classifies soil into two grades, multipurpose and specific-purpose topsoil. As well as topsoil grading, the standard also provides guidance on soil sampling and analysis, as well as handling and storage of soil.

Multipurpose topsoil is capable of sustainably supporting grass, trees, shrubs, herbaceous plants and other plantings, and is therefore suitable for the majority of landscape applications.

Specific-purpose topsoils are topsoils that have low fertility or are acidic or calcareous, and are specified when there is a particular specialist need. It should be noted that these soils are not appropriate for general landscaping applications and are more suited to particular ecological applications where a specific soil is used to obtain maximum biodiversity benefit, and therefore may be appropriate for particular SuDS applications.

When specifying topsoils, it is important to consider the predominant soil type in the locality and the intended use of the site, so that the properties specified are compatible with the requirements of the soft landscaping elements proposed. Wildflower areas require an impoverished (low phosphorus) soil with preferably a low weed seed bank, so fertile topsoils and most "natural" topsoils are less favourable than "manufactured" topsoils with a low seed bank.

29.5.2 Textural classification of soil

Texture describes the mixture of different particle sizes in soils, and names such as loamy sand and clay describe the constituent mix. Soils can also be referred to as heavy (clay/silty) and light (sandy) to indicate their ease of cultivation. Texture is a fundamental soil property which influences key aspects such as drainage, water storage, workability and susceptibility to soil erosion and thereby its suitability for different uses. It also plays a major part in defining the need and the strength of a soil's structure. Structure is the term used to describe the aggregation of soil particles (clay, silt, sand) into "peds" which can vary in size from small crumbs to large blocks.

The texture class of a soil is defined by its relative proportions of sand, silt and clay. The UK uses a system of classification developed by the former Soil Survey of England and Wales (**Figure 25.2, Chapter 25**). This is different from other classifications in use around the world.

Soil structure is more critical in heavy textured soils. Without a defined soil structure, clayey/silty soils tend to be less permeable and porous than sandy soils and as a result offer limited opportunity for infiltration within part of a SuDS scheme.

▶ For further information on soil texture, see Natural England (2008).

29.5.3 Topsoil manufacture

Multipurpose topsoil for general landscape use can also be made from a mixture of compost, sand and subsoil because manufactured soil provides a suitable alternative for sites where there are limited amounts of natural topsoil present on site. The process can be suited to bigger schemes where the economies of scale allow for blending of soils on site. Manufactured soils are a mixture of existing, available materials (sometimes including remediated soils from previously contaminated ground), with inorganic and organic materials such as PAS 100:2011 compliant green compost, to create a general-purpose or specific-purpose soil. Manufactured soils are also widely available to buy. Advice from a soil or landscape scientist should be considered to ensure that soils are blended to achieve the desired plant growth as well as being suited to the specific SuDS functions proposed.

PAS 100 is a specification established by the Waste and Resources Action Programme (WRAP), for composted materials produced by large-scale, licensed composting facilities that compost household and garden waste into usable compost. The Landscape Institute and WRAP (2012) have also developed another standard, specifically for landscape applications.

29.5.4 Use of fertilisers

Dependent on the quality of the topsoil being specified, certain fertilisers may be required, in order to obtain a nutrient level within the soil that will facilitate healthy and sustained plant growth. Soil fertility is represented scientifically by NPK values, which quantify the levels of nitrogen, phosphorus and potassium within the soil, and are essential for healthy plant establishment and growth:

- **Nitrogen** is an essential growth nutrient and is required for the growth of leaves and stems.
- **Phosphorus** is essential for root growth and development.
- **Potassium** performs an important photosynthetic function within the plant, while also promoting flower and fruit development.

The nutrient value of a soil can be ascertained through an appropriate soil test (as specified within BS 3882:2015) and specific fertilisers applied to restore a balance within the soil, ensuring that it will provide suitable conditions for successful establishment of the various plants, trees and grass.

Generally, bulk fertiliser comprising organic material will be used for new planting, with inorganic fertilisers of the appropriate NPK composition added to address any soil nutrient deficiencies. Inorganic fertilisers are only required for grass establishment, and wildflower grass should receive no extra fertiliser treatment (unless recommended through soil analysis due to either contamination or severe nutrient depletion).

Where fertilisers are used within SuDS, they should be worked into the soil during cultivation, rather than scattered on the soil surface, to reduce rapid runoff.

Use of fertiliser in the context of a SuDS should give due consideration to potential contamination of the receiving watercourse. Excessive or incorrect application of fertilisers can result in nutrients not being taken up by plants at the point of application and being washed downstream where effects such as algal bloom can occur in the SuDS themselves and/or the receiving watercourse. Slow-release fertilisers are preferable to soluble fertilisers.

29.5.5 Use of mulches

Mulches are used to aid plant establishment, primarily by covering the soil with a layer of material, which has the function of:

- preventing weed seeds from germinating and thereby competing with plants for light, space, soil, nutrients and moisture
- reducing evaporation of water from the soil, particularly during summer months when there may be prolonged periods without rainfall, but the plants are in active growth.

While soil evaporation is part of how SuDS function, this does not take priority during the plant establishment period, as it is more important to encourage the plants to achieve a sufficiently mature size, so that they can contribute effectively to the functional and visual quality of the system. Once plants are established, their ability to draw moisture from the soil outweighs any loss of evaporation from the surface due to mulches.

In landscape schemes designed for amenity purposes, chipped or pulverised tree bark is commonly used to mulch planting beds. However, within planting beds that are part of a SuDS, where there is a flow of water across a planted area or which has an outlet above ground, bark should not be used, as it will float down the system and accumulate around – or potentially block – the outfall. Similarly, beds mulched with a loose material such as bark should have their finished levels carefully considered when they are located adjacent to pervious paving, to ensure that the mulch does not wash off onto the paving.

Effective alternatives to bark mulch include gravels, pebbles or small rocks. Jute matting or other biodegradable materials can also be considered, provided they are aesthetically appropriate and do not break up into chunks that may block an outlet when they degrade. Such materials will need to be pinned down into the soil with steel pins or wooden pegs, and will ultimately be covered by the plants as they develop. These are particularly useful for plants that creep either by their roots, stolons or below-ground rhizomes.

29.6 CHOOSING THE RIGHT PLANTS

Planting within SuDS should primarily ensure that the plants selected are suited to the conditions in which they are going to grow, so that they will thrive and deliver the range of benefits required of them. In the public's eye, the quality of a scheme will be judged on its aesthetics, but while this is an essential factor in securing public support and acceptance for a scheme, it should be combined with functional suitability.

Primary consideration should be given to locally native species, and plants that benefit wildlife through their nectar, fruit or berries. The extent to which they are used on any site will be dependent on the purpose of the planting, its location and the requirements of both the local council through the planning process and the expectations of the public. The planting designer will also wish to have their input to the style and design of the planting.

Generally, the choice of plant species should reflect the usual design decisions relating to their location in terms of aspect, sun or shade, height, form, colour, whether evergreen or deciduous, native or ornamental, and soil factors such as pH, depth, nutrient status and organic content. However, the key consideration has to be their ability to withstand the fluctuations in soil moisture that will occur. Planting plans should be determined by landscape architects or others skilled in detailed planting design.

29.6.1 Restrictions and use of planting

The use of planting may need to be restricted due to their potential impact on adjacent structures – although this primarily relates to tree planting. The use of root barriers should be considered in relation to the proximity of trees to buildings, as well as guidance from the NHBC (1995), regarding soil types, tree species and foundations depths, although the coverage of species is limited.

Generally, the following constraints should be taken into account:

- Consideration should be given to the depth of soil within any lined system to ensure that it is sufficient for the plants or trees intended to grow there, and to avoid damage to the liner.
- Trees (or shrubs that ultimately grow to the size of small trees) should not generally be planted on water-retaining earth embankments.
- Trees should not be planted close to the inlet, outlet or other drainage structures where their roots may affect their structural integrity.
- Willows and poplar in particular should not be planted close to structures, pipes, paving, lined pools or water-retaining earth embankments. But they may be planted on the uphill side of natural ponds or lakes where sufficient space allows.

Conversely, planting is frequently used as a low-level barrier at the water's edge, as a measure to prevent the public – particularly, young children – from inadvertently falling or walking into open water. Planting should not obscure visual observation of the water (which can be important from both a safety and aesthetic perspective) or act as a barrier to rescuing children, should they find a way through.

29.6.2 Invasive species

"Invasive weed" is a term used to cover a number of native and non-native plants. While invasive native plants can quickly dominate sites, they are of much less concern than non-natives, that can significantly impact on our native ecosystems as they spread rapidly, grow strongly and are difficult to control.

The Wildlife and Countryside Act 1981 provides the legislative framework for managing non-native species, as it is an offence under Section 14(2) of the Act to "plant or otherwise cause to grow in the wild" any plant listed in Schedule 9, Part II, and doing so carries penalties of up to a £5000 fine and/or 2 years' imprisonment. Listed plants considered of relevance to working in or near fresh water are as follows:

- Japanese knotweed – *Fallopia japonica*
- giant hogweed – *Heracleum mantegazzianum*
- Himalayan balsam – *Impatiens glandulifera*
- Australian swamp stonecrop – *Crassula helmsii*
- floating pennywort – *Hydrocotyle ranunuculoides*
- creeping water primrose – *Ludwigia grandiflora*
- parrot's feather – *Myriophyllum aquaticum.*

Plants designated as invasive have in the past been notifiable to Defra, but they are now so widespread that this requirement has been abandoned. However, while these plants may be found on a development site, it is a criminal offence to allow them to "escape" its boundary, and they must be eradicated in accordance with the guidance provided by the EA (2010). While all these plants cause major environmental problems, giant hogweed can also prove dangerous to human health (poisonous sap from leaf and stem hairs causes blistering and persistent skin pigmentation). Similarly, Japanese knotweed must be eradicated before any construction or planting works, as it has the ability to regrow through paving or concrete and can seriously damage construction works. As most development sites will be subject to a Phase 1 Habitat Survey as part of the planning process, any such plants will be identified in the ecologist's report. Landscape professionals should also be able to identify Japanese knotweed, giant hogweed and Himalayan balsam as a minimum.

Plants listed as invasive and methods for their treatment can be found in EA (2010). The RHS has also produced a further list of plants from Schedule 9 that are now banned for use or sale at all RHS shows, as many have been part of normal commercial plant production for many years <**http://tinyurl.com/q5omga2**>. Those of particular relevance to avoid adjacent to water are:

- water fern – *Azolla filiculoides*
- curly waterweed – *Lagarosiphon major* (or *Elodea crispa*)
- water hyacinth – *Eichhornia crassipes*
- water lettuce – *Pistia stratiotes*.

There are also a wide range of plants (both native and non-native) that if left unchecked will tend to smother less dominant plants and reduce the planting scheme to a very limited number of species. Invasiveness can also be a product of the space available for the plants within the SuDS, as a large pond or lake may well be capable of supporting plant species that would dominate a smaller water feature, and so success will be dependent on the horticultural knowledge of the designer, an understanding of the SuDS component's intended use and the anticipated level of maintenance it will need.

Some plants associated with water bodies that are considered potentially dominating are:

- bulrush or greater reed mace – *Typha latifolia*
- lesser reed mace – *Typha angustifolia*
- common reed – *Phragmites australis*
- greater spearwort – *Ranunculus lingua*.

It should be noted that invasive plants can be easily transferred from one site to another through seeds, pieces of plant or contaminated water being transferred by humans or others. Methods to protect against this are described in detail by the NNSS (2015).

29.6.3 Biosecurity

Biosecurity considers the threat to our native flora and ecology as a consequence of introducing disease through plants, insects, viruses or other means. There has been wide public awareness of biosecurity issues for many years since Dutch elm disease destroyed almost all mature elms within the UK. Since 2012, Ash dieback (*Chalara fraxinea*) has been in the headlines, and over time the disease is expected to lead to the loss of most of our ash trees and significant alterations to the landscape character of many areas.

Chalara is, however, only one of a rapidly growing number of pests and diseases threatening the urban and rural landscapes of the UK, as there are pests, viruses or fungi that affect oak, willow, alder and a wide range of other plants, although most are not fatal. Early government policy development around *Chalara* has been heavily focused on forestry and woodlands, both in terms of the threats to production and the impacts on ecology, although the effect will clearly be much wider.

Care is therefore needed in both the choice of plant material and its procurement, to ensure that it is free from, or resistant to, all currently known diseases (some of which are only found is certain parts of the country). A requirement for plants to be of UK provenance can be considered, but may not always be possible to achieve. Imported plants pose the greatest risk, although government requirements for border controls, alongside certification in the exporting country, are helping to address this problem. Recent experience has also shown how some diseases are airborne and are therefore able to cross borders despite a ban on importation. It is therefore essential that any species known to be at significant threat of disease are not used within any new schemes until resistant strains are developed.

29.6.4 Plant specification and purchasing

All plants should be specified in line with BS 3936-1:1992, and using the National Plant Specification (NPS) – a design software tool <**www.gohelios.co.uk**>. This identifies a wide range of species that are commercially available, and the sizes in which they are normally grown. It is essential that planting is specified in line with this document to ensure that it is likely to be commercially available. This is particularly important where plant lists are included on drawings for submission to the planning authority. While there are specialist nurseries for particular ranges of plants which it may be possible to specify, care should be taken to ensure that these will be available in the numbers required at the time they are needed on site, as many specialists do not produce large quantities of plants, so their plant lists can be deceptive. Plants should always be specified using their full botanical name (in Latin), as common names are too variable, and many plants do not have them.

The major nurseries generally participate in the Horticultural Trades Association Nursery Business Improvement Scheme (replacing their old Nursery Accreditation Scheme) <**http://tinyurl.com/plot7s3**>, working to ensure that nurseries are upholding standards of performance and product quality. Specifications should generally state that all plants should be supplied by enrolled suppliers. This will ensure that the nursery does not substitute alternative plant species or sizes without prior agreement, and they should produce good quality, disease-free plants. Many of the smaller nurseries may not be participating, but provided their quality control and production are acceptable, they may well offer a more extensive range of alternative plants.

Plants may be purchased all year round, but many aquatic plants are only available in any quantities as “bare root” stock during May–July, and many will not be available during the winter. Woody plants are also generally purchased as bare root stock in the dormant season over winter. Most damp species and general landscape plants will be available throughout the year, although stock may be limited at the end of the season. Advance ordering to secure a confirmed supply is recommended.

29.6.5 Selecting the right plants for SuDS

Consideration of the right plants for a SuDS will depend on two issues, over and above normal plant selection procedures:

- What is the moisture regime likely to be in the SuDS? This will determine the tolerance of plant selected, and whether a dense rooting system is desirable.

- What is the general water regime for damp or wet SuDS planting? This will depend on the frequency of saturated conditions and the average depth of water.

Table 29.1 illustrates the expected moisture regime by type of SuDS component, and the tolerance level required of the plants.

It should be noted that there are many plants and trees suitable for SuDS that are tolerant of a wide range of conditions.

The plant selection should also consider visual quality all year round. While large-scale water features will contain elements that are herbaceous and die back each winter, or are deciduous, smaller scale features in urban or suburban areas should contain a higher percentage of plants that are evergreen and those with attractive winter features, such as interesting bark, catkins or berries. Grasses are useful as they provide a dense creeping rootzone that is resilient, weed proof and evergreen. Plant selection should also consider the necessary maintenance requirements of the plants, and the level of funding/skill that will be available to maintain them.

Planting design should be undertaken by a landscape architect, horticulturalist or other professional with the appropriate skill and knowledge in planting.

TABLE 29.1 Plant tolerances and constraints in SuDS

SuDS component	Moisture regime	Plant tolerance	Plant restrictions
Systems that are NOT normally wet			
Planted swale in natural soil	As determined by the natural soil, but with occasional inundation	Any plants that are tolerant of a wide range of conditions, wet or dry	No restriction on use of trees or size of plants selected
Underdrained swale with planted surface	As determined by the natural soil, but dryer around the drain with occasional inundation	Any plants and drought-tolerant species	Trees to be planted in natural soils on banks, and plants at the edge of underdrain and/or on banks
Rain garden or bioretention area with constructed soil	Generally dry with occasional inundation	Drought-tolerant plants and those known to have at least reasonable tolerance	Sufficient soil should be provided to support the ultimate size of any tree planted (**Chapter 19**)
Detention basin	As determined by the natural soil but with occasional inundation	Any plants that are tolerant of wide range of conditions, wet or dry	No restriction on use of trees or size of plants selected
Systems that are normally wet			
Pond or wetland	Permanently saturated	Prefer to be submerged at depths > 450 mm	Trees unsuitable
		Grow in submerged zones from the permanent water level to depths of up to 450 mm	Limited tree species only, and constraints regarding planting on retaining banks
	Mostly saturated but always damp	Grow in damp conditions that usually exist at the permanent water level and up to 150 mm above that level	Limited tree species only, and constraints regarding planting on retaining banks
	May vary from wet to dry, although the root systems will reach into the damp/ wet zone	Tolerant of a range of conditions that usually exist between 150 mm and 300 mm above the permanent water level	Wider range of tree species, and constraints regarding planting on retaining banks

29.6.6 Use of native plants

Native plants should form the backbone of any SuDS planting scheme because of their value in providing habitat and increasing biodiversity. However, smaller-scale SuDS components in suburban or urban areas may offer fewer opportunities for native planting, where year-round visual quality requires a higher percentage of evergreen plants or where natives do not provide a sufficient range of smaller growing plants. However, efforts should be made to include native plants in all schemes and, wherever possible, to maximise their number.

The use of native plants, and ideally plants of native provenance, is particularly important for SuDS components that discharge into natural water systems, owing to the risk of introducing further exotic (and potentially invasive) plants into the natural environment. Where schemes outfall to a surface water or combined sewer this is of lesser importance, and if a site manages water completely by infiltration, then the risk of escapes is very low.

▶ Biodiversity is discussed in detail in **Chapter 6**.

29.6.7 Establishment issues and natural regeneration

Natural regeneration should be considered as an appropriate method of plant establishment, as the natural seed resource in the soil will reflect the local landscape's plants, and what will grow there naturally, although not necessarily within the SuDS. However, a balance may need to be struck between the need for an immediate visual impact and allowing areas to regenerate. Wetlands establish particularly quickly through natural regeneration, and plants will colonise those parts of the site to which they are most suited. Management would then ensure that any unwanted or invasive species were removed. The speed at which natural regeneration will occur will also depend on a number of factors:

- nutrient levels in the soil
- previous use of the ground and therefore
- seed resource within the natural soils
- proximity to an existing seed resource (even local ditches would provide a suitable seed resource)
- use of direct seeding of parts of the wetland, and then allowing this to naturally seed other parts (particularly useful if an area is being developed in phases)

Seed is spread naturally primarily by wind dispersal, but also by wild animals, insects and birds, as well as on the boots of walkers. Damp areas can also be effectively established via a mix of natural regeneration, wildflower seeding and some interplanting, which provides some immediate cover, but mainly relies on regeneration. The techniques selected will depend on the time available for establishment, and when the system needs to be fully functional, alongside the need for a level of visual acceptability for users once access if provided.

Historically, a way to stimulate regeneration has been to introduce "bucketfuls" of mud taken from the margins of existing ponds, which had the benefit of introducing beneficial microorganisms as well as plant seed. However, the increasing problem of invasive species has severely limited this practice, owing to the risk of their inadvertent spread. However, it may be considered appropriate where an existing pond has been monitored and is known to have no invasive species, or where a new pond is being developed on an existing site where the background of the pond's ecology is known. Advice on this should be sought from an ecologist, but, if in doubt, do not use this practice.

29.6.8 Establishment of plants

All planting operations should be specified in accordance with BS 3936-10:1981, and the requirements related to seasonality, weather and soil conditions, soils, fertilisers, bed preparations, use of fertiliser and mulches, plant handling and planting and the use of all planting ancillaries, such as stakes, ties and guards, should be clearly specified.

29.6.9 Defects liability for planting

All planting carried out under a formal contract – the best form suited for planting contracts being the JCLI (2012) form of agreement – should have a defects rectification period of 12 months, to ensure that the planting has fully established through both its dormant and growing season. Contract conditions should require that any plants that fail during at least the first year (barring vandalism or other exceptional reasons) will be replaced free of charge by the landscape contractor. Where semi-mature trees are used, this period may extend to 2–3 years. However, liability can only be enforced if the contractor who undertook the planting is given responsibility for its maintenance during this establishment period. Where general construction or engineering contract forms are used, appropriate clauses will need to be written into the contract.

29.7 GRASS

It is essential that areas of grass within a SuDS are established properly before being inundated with water, as areas that do not have sufficient grass cover may suffer soil erosion, or damage may be caused to the developing sward. The timing of the implementation of the SuDS is therefore key in determining how the grass sward is best achieved, and whether any temporary diversion of surface water is possible or practical until the grass is sufficiently well established to receive surface water. Grass areas that are established early in the construction process, should be kept free of all debris or waste building materials or site water contaminated by construction use.

29.7.1 Phasing and site considerations

Ideally grass areas would be sown and allowed to develop for 3–6 months in advance of being brought into active use. However, space restrictions on site may mean that this is not practical. Seasonality will also determine the constraints to producing the necessary grass cover. Ideal methods of growing grass will also depend on whether an amenity grass area is required, or wildflower grass.

The cheapest option (and best if undertaken correctly) is to seed, and is economically the only practical option on larger sites. However, grass can only be sown in the growing season when the soils are sufficiently warm and damp to allow germination. While there are guidelines for sowing, these timings may be reduced or extended in any year dependent on the actual weather conditions. Also note that sowing in the middle of summer is likely to be highly dependent on very regular watering if the summer is dry – but then if drought conditions are declared, watering may not be permitted.

Table 29.2 identifies the constraints governing grass establishment and the options that may be considered.

Where early establishment of grass SuDS has not been possible, and they are required to be utilised fairly soon after construction/planting, then consideration should be given to turfing (say) the base of swales, but seeding the sides, above anticipated normal water levels. Where wildflower grass is desired (but wildflower turf is not affordable), amenity turf can have wildflowers plugged into it once established, while seed from adjacent wildflower areas will gradually seed in naturally if the site conditions are suitable.

29.7.2 Selecting the right seed mix

A wide range of seed mixes are available, and turf can also be grown to the individual producer's own seed specification. Advice can be sought from the suppliers related to soil type, pH, moisture, whether sited in sun or shade and the proposed use. Low-maintenance mixes that require less cutting may be appropriate, or specific sports mixes for detention basins intended to be used for field events. Consideration should also be given to seed provenance, particularly for wildflower mixes, to ensure that the species mixes are suitable and of native origin.

TABLE 29.2 Factors and constraints governing grass establishment methods

Establishment method	Type of grass	Relative cost	Season for sowing/laying and establishment period	Watering requirements	General comments
Seed	Amenity	Low	Sow from early April until end of October; establishment can take 8–16 weeks, depending on time of sowing	Likely to be required during the germination period and until the young plantlets are sufficiently well established because they are easily damaged by drought; seed on waterlogged soils is liable to rot	Can produce the best quality finishes, but requires very good preparation, protection and maintenance during establishment
Seed	Wildflowers and grass either spring or summer flowering	Medium	March/April or September/early October, but soils should not be waterlogged; some wildflowers need cold weather to break dormancy, so may not germinate for nearly a year, depending on when sown	Generally only required for the grass element and establishment; seed can rot if too wet/inundated before germination	A wide range of proprietary mixes are available that can be used in wet or damp conditions, or for banks which may experience occasional inundation; bespoke mixes are also available; some seeds may require to be subject to frost for the seed to break dormancy
Turf	Amenity	Variable medium/high	Can be laid all year round, provided the ground is not waterlogged, frozen or covered in snow; rooting down can take 3–8 weeks, depending on time of year and weather conditions	Essential for establishment, although unlikely to be required in winter or in cooler wetter conditions	Generally provided as turves, but can be supplied as large rolls; universally available in a range of qualities and prices, from treated meadow grass through to low-maintenance mixes or high-quality amenity mixes
Turf	Wildflowers and grass	Very high	Some suppliers now have turf available all year round; it can be laid providing the ground is not waterlogged, frozen or covered in snow, and will take up to 6–8 weeks for plants to root down, depending on weather conditions	Essential for establishment, although unlikely in winter months, but not required post establishment	Generally provided in rolls rather than turves; may not be available in large quantities unless pre-ordered or contract grown, so potentially long lead-in time; some suppliers provide bespoke mixes

29.7.3 Amenity grass

Amenity grass may be used in situations where occasional inundation is planned, such as swales or grass detention basins. Here, it is expected that any standing water will drain away within 24–48 hours. A standard robust amenity mix is therefore likely to be adequate. Mixes containing finer turf grasses are generally less likely to be able to withstand repeated inundation. Turf can be supplied as individual turves or in larger rolls. Local supplies of cultivated meadow turf (meadows that have been sprayed with herbicide to kill most field weeds) are generally available, but this is much more variable in its quality, although it is often sold as a cheaper alternative.

29.7.4 Wildflower grass

A range of wildflower grass seed mixes are commonly available. Care should be taken in the provenance of wildflower seed, as much seed is produced abroad, and is not necessarily suitable for use within the UK due to its impact on our native flora – see also **Section 29.6.3** on biosecurity. Mixes are generally a combination of grass and wildflower seeds, and can be selected to reflect the type of habitat required, existing species, the soil pH and the likely degree of inundation it will receive. Wildflower seed can also be purchased without grass seed, but these tend to be for specific applications. Wildflower seed mixes should reflect existing species. Custom-designed seed mixes can also be produced for sites if there is a particular plant ecology that is required. Such mixes may have been proposed by the ecologist as part of a Phase 1 Habitat Survey, on sites where this is appropriate, or may be developed to reflect the typical species mix in local meadows.

Almost all wildflower grass is produced from seed, but turf can also be bought. This is relatively costly, but may be appropriate in specific locations, although this is only available from a few specialist suppliers. Previously, wildflower turf was lifted slightly thicker than normal turf, as it requires a greater depth to allow the wildflower root systems to be cut and lifted without causing damage, but most turf is now grown on plastic trays, which produces a strong mat of roots below the bottom of the turf. This encourages rapid establishment, provided the turf is well watered.

Wildflower grass can also be created by overseeding and interplanting existing grass areas, but can take several seasons to achieve. One of the main problems is that the existing grasses can be very vigorous and may out-compete wild flowers. A method to reduce the vigour of established grassland, is to introduce semi-parasitic plants such as *Rhinanthus* species (rattle), *Euphrasia* species (eyebright) and *Pedicularis palustris* and *P. sylvatica* (lousewort). The most useful is *Rhinanthus minor* (yellow rattle). In late summer or autumn seed is broadcast onto grass that has been cut short. As it is an annual it can be eliminated from grassland in a year if prevented from seeding by cutting it down once flower heads have formed.

29.7.5 Reinforced grass for access

Grass may be reinforced to provide a more durable surface for access. The presence or absence of a mesh backing should be stated in the grass specification. It should be noted that some grass seed mixes are also more suitable for heavy wear than others, and may be adequate on their own, dependent on the anticipated frequency and weight loading. Amenity grass that is grown with a fine plastic mesh backing is not considered to be "reinforced" – this assists in allowing turves to be cut thinner with less soil, and be more able to withstand handling, but does not provide any structural reinforcement.

Reinforced grass is generally used:

- to provide access for heavy machinery within SuDS where a continuous grass surface is required
- to provide a permeable surface for parking
- for areas of heavy foot traffic.

▶ Further guidance on bioengineering for reinforced grass for use on banks and slopes is given in **Section 29.4**.

The construction materials that provide structural stability for grass need a suitable substrate and turf, or a seed mix that is appropriate for their particular reinforcement technique. Establishing a good quality grass sward is particularly important, both to provide an attractive appearance, and to ensure that the surface is sufficiently even for pedestrians. Typical reinforcement techniques are:

- rigid concrete or plastic units
- flexible polypropylene cellular sheeting
- plastic mesh
- substrate containing mesh reinforcement fibres.

All of these options, with the exception of the plastic mesh, may require a sub-base layer, dependent on the weight loadings anticipated, along with positive drainage as part of the sub-base design in accordance with the respective manufacturer's recommendations. Where sub-bases are used, the amount of soil available in the cellular or rigid units is reduced to what can be provided within the containment system alone. This can allow little space for the grass to root, and will make it more vulnerable to drought. The nutrient supply for the grass will also be low and will require fertilising to maintain a good quality cover.

The most important factor for establishment is creating a good friable seed bed. Hard-wearing grass species should be used with an ability for the seed to adapt to changing circumstances with some degree of drought tolerance, shade tolerance, tensile strength and binding abilities. Clover might be a useful addition if the lawn needs to look after itself, as it enhances the ability of sward to withstand stress, such as lower nutrient content. Use slow-release fertiliser in the seed bed and (at least) annually for an established lawn where volume of substrate is low or likely to be of low nutrient status.

Generally seed or turf can be used for most reinforcement products, and the various parameters are summarised in **Table 29.3**.

Where turf is used, it would ideally be grown on a soil with high sand fraction to ensure integration with the substrate below.

29.7.6 Establishment

Wildflower areas require an impoverished (nutrient poor) soil, so topsoil should not be used as the main substrate. Also note that if the soils are naturally very fertile (or are currently arable land), wildflower meadows may not be appropriate, and would be very difficult to establish, and would require long-term management to establish properly. Depending on the quality and condition of the subsoil, a skim of topsoil may be required to provide a good quality tilth and to aid germination.

All grass is vulnerable to drying out and deterioration during the establishment period. Turf in particular should only be imported to site in sufficient quantities that it can be laid as soon as possible after delivery, and should be handled, stored and protected during this period. Watering will be essential during the establishment period, unless the soil is already moist, and rainfall is expected. Areas should not be over-watered, as it may wash out parts of the seed bed or may waterlog the turf, potentially damaging its root system.

29.8 DESIGNING FOR MAINTENANCE

While overall maintenance operations are dealt with in **Chapter 30**, maintenance considerations that influence how a scheme is designed should be developed in tandem with the scheme. It is important that the principle of who will maintain a site, and the anticipated resources likely to be available to do so, are anticipated from the outset. As the soft landscape may be delivering part or all of the drainage for a site, this should be treated as part of the site's infrastructure, with the necessary operations planned accordingly. As the SuDS will normally form part of a larger landscape scheme, the two elements should be completely integrated within the design, and (ideally) maintained jointly to avoid any areas being missed or maintained to a different regime. Visual quality and hydraulic performance should both be addressed within the management and Maintenance Plans.

TABLE 29.3 Parameters for grass reinforcement

Reinforcement product	Requirement for sub-base	Adequacy of substrate for grass	Suitability for seeding	Suitability for turfing
Concrete cell units	Always, but dependent on weight loading	Cells small because thickness of concrete allows little rooting area; may need proprietary "soil" to fill due to unit size	Yes	No
Rigid plastic cell units	Depth dependent on weight loading	Cells small but plastic takes up smaller percentage of area; may need proprietary "soil" to fill cells due to unit size	Yes	Manufacturers generally suggest seeding
Flexible polypropylene cellular sheets	Dependent on weight loading, may not be required	Good, large cell width and depth, can be filled with natural soils if sufficiently friable	Yes	Yes – although manufacturers generally suggest seeding
Plastic mesh	No	Very good as laid on natural soil	Yes – mesh to be laid within seed bed, pinned down and lightly covered with soil before seeding	Yes – mesh pinned down over turf; can be added to existing grass areas, but hard to get good integration with soil surface
Substrate with mesh reinforcement fibres	Dependent on weight loading, may not be required	Good volume but low nutrient status	Yes	Yes – although manufacturers generally suggest seeding

29.8.1 Aligning the design for ease of maintenance

Enabling adequate access to the various parts of the SuDS for the equipment that needs to be used to perform the maintenance, is a key design criterion, but one that is frequently forgotten. Where large-scale equipment is required for works around inlets and outlets or other features, then dropped kerbs and paved or reinforced grass landings will be required at strategic points from roadways, and ramps down into basins may be required for larger detention basins. These should be sized to suit the sort of equipment that will be required, including mowers for regular maintenance.

Understanding who will maintain a site can also influence design. Sites to be adopted by local authorities may be subject to term contract maintenance agreements that will have specified maximum gradients on which their equipment may be operated. These may typically be 1 in 5 or 1 in 6 slopes, which can significantly affect the ground modelling or use of areas of closely mown grass around the SuDS. Alternative options in this instance would be to use steeper gradients, but use planting or wildflower grass. Bed layouts should be designed to ensure that the margins are sufficiently flowing to allow machinery to mow easily around them. Where maintenance companies use a wide range of mowing equipment, there is less need for such stringent considerations.

However, even with smaller mowing machines, grass banks can only be cut by ride-on or wide hand-operated mowers up to 1 in 4 slopes; the maximum slope for any form of hand-operated equipment is generally taken as 1 in 3, but this should be subject to risk assessment, which considers the capability of the particular cutting machine. Cutting steeper slopes or banks is likely to require a tractor with a side-arm flail, as pedestrian-operated machines are unsuitable. Domestic-scale rotary mowers and handheld strimmers are unlikely to be practical for extensive areas of grass.

Cutting grass can also only be done effectively when the ground is dry, so areas intended to be damp on a regular basis should have the choice of surface vegetation carefully considered, as close mown grass is unlikely to be suitable.

There are restrictions on the use of chemicals adjacent to watercourses, so only approved herbicides or pesticides should be used, and these operations should only be undertaken by those qualified in their use.

29.8.2 Management plans

Management plans for the first five years after planting are usually required as a standard landscape condition to a planning consent, but these essentially cover "establishment maintenance" and do not address the issues of long-term maintenance. Longer-term management plans should be established for all sites, but particularly where those involved in its initial design and establishment are unlikely to have a longer-term involvement. This will ensure that specific requirements related to how the SuDS function as a planted system will be identified within the plan.

Detailed guidance on the production of management plans is provided in **Chapter 30**. Generally, the overarching aims and objectives should be established, and the plan worked through from the broader landscape setting and its objectives, down to the detailed maintenance operations. Review of the performance of the SuDS and the effectiveness of maintenance should be undertaken on a regular basis, and the plan reviewed in line with its findings, bearing in mind the original overarching intention of the SuDS and the broader landscape in which it sits.

29.9 REFERENCES

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STATUTES

Acts

The Hedgerows Regulations 1997 (No.1160)

Wildlife and Countryside Act 1981 (c.69)

British Standards

BS 3882:2015 *Specification for topsoil*

BS 3936-1:1992 *Nursery stock. Specification for trees and shrubs*

BS 3936-10:1981 *Nursery stock. Specification for ground cover plants*

BS 5837:2012 *Trees in relation to design, demolition and construction. Recommendations*

PAS 100:2011 *Compost specification*


Image courtesy JPP Consulting

30 MATERIALS

Contents

Chapter 30

Materials

This chapter provides guidance on certain soils, aggregates and geosynthetics that might be used in SuDS design.

Materials that are specific to a particular SuDS component (eg bioretention soils, sub-base below pervious surfaces, filter drain materials) are discussed in Chapters 11–23.

Topsoil, subsoil and other landscape materials are covered in Chapter 29.

▶ *Guidance on good landscaping practice is discussed in Chapter 29.*

30.1 INTRODUCTION

This chapter considers the following types of general materials or products that may be used in SuDS:

- **soils and aggregates** – used as drainage layers or as engineered soils below basins, filter strips, swales etc
- **geosynthetics** – geotextiles, geomembranes, erosion control products (including products made with natural materials such as coir)

There are recognised and accepted specifications for most of the materials or products, which have been developed over many years. It is preferable to use existing specification clauses wherever possible, rather than having an array of different bespoke specifications. There should be allowance within the specification to insert site-specific, performance-based values for key properties.

A list of the most common materials used in SuDS and relevant chapters of this Manual where further information on their use can be found is provided in **Table 30.1.**

TABLE 30.1 Common materials used in SuDS

Material	Included in this chapter	Further information
Soils		
▪ topsoil	✓	Chapter 29
▪ engineered soil	✓	
▪ bioretention filter media	✓	Chapter 18
▪ structural soil (for tree pits)	✓	Chapter 19
Aggregates		
▪ filter drain materials	✓	Chapter 20
▪ permeable sub-base	✓	
▪ pipe backfill and surrounds	✓	
▪ drainage layers	✓	
Geosynthetics		
▪ geomembranes	✓	
▪ geotextiles	✓	
▪ geocomposite clay liners	✓	
▪ erosion control products	✓	
Pipes and tanks used for storage (plastic pipe, concrete pipes, geocellular tanks, etc)	✓	Chapter 21
Landscape products (mulch, fertilisers, herbicides, etc)	✓	Chapter 29

30.2 STANDARDS AND CERTIFICATION SCHEMES

The Construction Products Regulations cover all materials used on construction sites that have a harmonised European standard (hEN), including the use of aggregates and geosynthetics in SuDS. If a product is covered by an hEN, it must meet the following requirements:

- The product must be CE (Conformité Européene) marked.
- The product must have a Declaration of Performance (DoP). This includes details of the product, relevant hEN and information about its performance in relation to the essential characteristics defined within the harmonised technical specification. Note that datasheets are not CE controlled documents and the DoP is the definitive product performance document.
- Testing of materials and products should use test methods published by the Comité Européen de Normalisation (CEN). These test standards are given a British Standards (BS) designation and published by the British Standards Institute (BSI). Test laboratories may be accredited for each specific test they undertake. One accreditation service is the UK Accreditation Service (UKAS), and they provide a list of accredited laboratories on their website and the tests that are covered <**http://tinyurl.com/phfhzyc**>.
- CE products should be delivered with an accompanying CE certificate or made available for immediate electronic download (available in law to the customer but not anyone else such as a designer where he is not the purchaser).

Some products may not be covered by harmonised product standards (eg cellular confinement systems used for tree root protection and surface erosion control mats) and therefore do not have to be CE marked. However, it is possible to voluntarily CE mark a product not covered by an hEN by using a European Technical Assessment (ETA). This is an approval based on testing carried out to an agreed level with the "notifying body".

In practice, manufacturers or suppliers declare a defined set of properties of a product, as required in the relevant European Standard, plus any additional characteristics that have been measured and/or verified following a documented procedure.

CE marking is a self-certification scheme that indicates that a product conforms to relevant European Commission Directives and that the properties match those published by the manufacturer. It will allow checks on site to determine the manufacturing origin of the product and its batch number and offers the opportunity to request the factory quality control data for that batch of material. By providing a DoP, the manufacturer assumes legal responsibility for the conformity of the product to the relevant hEN.

CE marking should not be used on its own to determine if a product is suitable for a given application. It is an indication of quality control during manufacture, but it is no guarantee that a product is right for any given application. For example, a damp-proof membrane can have a CE mark, but it does not mean that it is suitable as a waterproof membrane below the sharp aggregate of a permeable pavement. Further information on the requirements of CE marking is provided by the British Standards Institute (BSI, 2008).

Fitness for purpose can be assessed by third-party accreditation. However, third-party accreditation certificates (eg British Board of Agrément – BBA) should also be used in an appropriate way. Simply asking for a product with a BBA certificate does not give adequate assurance that a product is suitable for a particular use. The BBA certificate should be checked for each specific application to make sure that the requirements in the certificate are being followed during installation (eg many BBA certificates for membranes specify the use of protection layers to prevent damage) and that the designer's requirements are being met.

30.3 GENERIC APPROACHES TO MATERIALS SPECIFICATION

The three most commonly used specification documents are summarised in **Table 30.2**.

TABLE 30.2 Commonly used specifications

Specification	Comments
National Building Specification (NBS)	▪ refers to the SHW for many earthworks materials and aggregates ▪ not necessarily performance based and allows reference to specific products and manufacturers' references ▪ available at a cost ▪ well established and widely used by engineers, architects and landscape architects.
Specification for Highway Works (SHW) (HA, 2005a)	▪ can be freely downloaded ▪ recipe or performance based ▪ well established and widely used by highways authorities and many developers and engineers; not commonly used by landscape professionals ▪ provides a robust specification for drainage, earthworks and pavement materials; NBS uses the SHW as a reference for many of these items ▪ generally updated every quarter.
Civil Engineering Specification for the Water Industry (CESWI) (WRc, 2011)	▪ performance- and recipe-based specification (does not refer to specific manufacturers) ▪ available at a small cost ▪ well established and used in civil engineering contracts let by water companies across the UK.

None of these currently include specific clauses for SuDS construction. However, they do contain clauses for most of the common construction activities and materials used in SuDS, or provision for including them. The different items required for SuDS will be found in different parts of each of the standard specifications, but this is not unusual for any item of construction. For example, if specifying materials for a car park surface and drainage using the SHW, the designer would call upon several different parts of the SHW (HA, 2005a), eg Series 500 (HA, 2009a), Series 600 (HA, 2009b), Series 700 (HA, 2009c) and Series 3000 (HA, 2009d). HA (2005a) will, in turn, reference various other standards as necessary.

The following principles should be followed when preparing specifications for SuDS:

- The specification should be performance- or recipe-based (never both for the same property) and should avoid the requirement to use products from a specific manufacturer, unless absolutely necessary. The designer should be able to provide justification for any particular specification requirement.
- The specification requirements should consider the construction phase and maintenance phase of SuDS.
- Performance requirements should be based on site-specific estimates of requirements. They should not be a repeat of values from a single manufacturer's literature.
- Wherever possible, the specification clauses should reference relevant British/European standards.

Any of these specifications can be adapted to include the specification clauses for specific SuDS components. An important consideration is that those involved in a project are familiar with the particular specification being used and that standard documents are subject to change outside the user's control. The version of a document being used should be stated, and users should regularly check for changes and updates to specifications.

Specifications should also take account of the Construction Products Regulations 2013 (**Section 30.2**).

30.4 SOILS AND AGGREGATES

Soils and aggregates are used in SuDS as drainage layers, storage layers or as general engineered soils below basins, filter strips, swales etc. If recycled materials are used, they need to meet the same specification requirements plus any additional requirements for the particular material. WRAP provides guidance on quality protocols for the use of recycled materials in construction projects (WRAP, 2014).

30.4.1 Aggregates for drainage layers and trenches

BS EN 13242:2002 defines aggregates that can be used in unbound granular materials, which will include drainage layers or filling for drainage trenches. The document provides aggregate properties, category ranges and methods of test that apply to any aggregate type satisfying BS EN 13242. Specifications will need to define suitable categories for properties that are relevant to the particular end use. There is a guidance document available that explains how to apply BS EN 13242 for aggregates, and provides recommended categories for different end uses.

Standard materials are defined in terms of the lower and upper particle sizes. For example, 20 mm single size material is defined as 10/20 (the minimum particle size is 10 mm and the maximum is 20 mm).

Aggregates used as drainage layers or in trenches need to be sufficiently permeable to drain water through them and may also be required to store water temporarily. The volume of air voids between aggregate particles in a layer of material will be important, because this is where water is stored or conveyed. Permeability can be severely affected by the percentage of fines (< 0.063 mm), for example 5% fines can in some instances decrease permeability by 95% depending on the overall grading of the material. If the drainage layer is to be used to support traffic, the aggregate needs to be sufficiently strong and durable to prevent it from breaking down into smaller pieces. Commonly used materials are set out in **Table 30.3**.

TABLE 30.3 Materials used as drainage layers or in drainage trenches for SuDS

Drainage application	Commonly used materials
Drainage layers	▪ Coarse graded aggregate 4/20 and 4/40 as defined in BS 7533-13:2009 – see **Chapter 20, Table 20.13**. This table specifies particle size distribution (or grading), There are a number of other important properties that are defined in BS 7533-13 including resistance to fragmentation, resistance to wear, durability, shape, water absorption and leaching of contaminants. ▪ Type 3 sub-base (as defined in the SHW) – see **Table 20.13**. Note that this is an aggregate that is defined in BS EN 13285:2010), and as this is not a harmonised standard, products that meet its requirements are not required to be CE marked at present. Both materials are suitable for use as storage layers below trafficked areas, provided that the overlying pavement and the drainage layer are designed to support the necessary loads. The resistance to fragmentation and resistance to wear of aggregates can be determined using Los Angeles and micro Deval tests, as described in BS 7533-13:2009. The water absorption and magnesium soundness properties are also important to assess degradation in freezing conditions.
Drainage trenches	▪ Type B filter drain material, as described in Table 5/5 and Clause 505 of HA (2009a).

Permeability of materials can be determined using the method described in HA (1990).

The percentage of voids in an aggregate is used to estimate how much storage it will provide and is called the porosity. Void ratio is often confused with porosity. The void ratio is the ratio of the volume of voids to the volume of solids in a material. It is a different parameter but is related to the porosity by the following equation:

$$\text{Void ratio} = n/(1 - n)$$

where n is the porosity.

Normally a value of 30% is assumed for the porosity of most aggregates used to store water in SuDS (ie 1 m^3 of aggregate can hold 0.3 m^3 of water). Experience has shown that materials meeting the grading requirements for coarse graded aggregate 4/20, 4/40 and Type 3 sub-base have a porosity of at least 30%. However, if a higher value is used in design, or other materials are used, tests to determine the porosity of material delivered to site should be carried out to make sure that it meets the value used in design. The tests should be undertaken on suitably compacted samples of the material. The compaction and porosity should follow the test methods in BS 1377-2:1990 and BS 1377-4:1990 that are relevant to the material being assessed. Care has to be taken when considering the porosity of materials with a significant proportion of fine sand, silt and clay particles. For example, quoted values of porosity for inorganic clays, silty clays or sandy clays of low plasticity vary from 29–41% (based on data from Geotechdata.info, 2013). However, water cannot move in and out of these materials easily, because they have a low permeability and they would not be suitable as a storage layer. Therefore, the porosity should always be considered alongside the permeability.

Construction of a drainage layer using 4/20 aggregate is shown in **Figure 30.1**. The exposed drainage layer is on the right-hand side and is partially covered by a separation geotextile on the left-hand side. The picture demonstrates the good housekeeping that is required on site during construction to keep the drainage layer free of mud or other debris that could clog it.

Figure 30.1 Construction of a drainage layer (courtesy EPG Limited)

30.4.2 Engineered soils

A suitable depth of engineered soil can be used over the bottom of basins, filter strips or swales to reduce waterlogging and improve the drainage characteristics of the basin. (Note that in BS 3882:2007, multipurpose topsoil can still be specified for banks of swales and basins, where planting is desired.) The engineered soil will tend to be a greater depth than typical topsoil depths – potentially replacing some of the subsoil depth, where appropriate. The important properties of this engineered soil are as follows:

- sufficiently permeable to allow water to drain easily
- having suitable properties and organic content to support plant growth.

An engineered soil will tend to be a sand-based medium with a narrow particle size distribution, high permeability and porosity, and reasonable reserves of organic matter and available plant nutrients. The example specification for a bioretention filter medium provided in **Chapter 18, Box 18.3** is a suitable soil type that could be considered. Root zone materials, that is a mix of sand and topsoil or green compost (similar to that used in the construction of sports pitches), can often also be suitable. Any specification that is used should be fully verified to ensure that it meets site-specific requirements in terms of drainage performance and its function as growing media. In particular, the saturated hydraulic conductivity of the soil should meet the design requirements for the drainage function.

30.4.3 Use of recycled and secondary materials as aggregates

Recycled materials can be used to produce aggregates for use in SuDS, provided that they have suitable properties. They can be obtained at source from demolition (eg bricks and concrete), highway maintenance (eg asphalt planings) and other works, or they can be bought from central processing centres. The quality of the recycled aggregate is dependent on the quality of the original source materials that are processed, and the processing that these materials undergo. All recycled materials must conform with the relevant specifications.

Secondary materials are waste products from other processes or are manufactured from waste products, for example blast furnace slag, recycled glass and recycled tyres.

The European standards for aggregates discussed above do not discriminate between different sources, and are for *"aggregates from natural, recycled and manufactured materials"*. One of the most common recycled materials is crushed concrete. When used in drainage layers or filter drain backfill, crushed concrete should meet the same requirements as natural materials.

It is important that recycled materials will not degrade in service and will not leach pollutants into surface water.

The use of recycled and secondary aggregates should comply with all relevant waste management and other environmental regulations. Further information is provided on the AggRegain website <**http://aggregain.wrap.org.uk/**>

30.5 GEOSYNTHETICS

There are many types of geosynthetics used in SuDS. These include geotextiles, geomembranes, geocomposite clay liners and geocomposite drainage products. Erosion control products (eg products made with natural materials such as coir) are also included in this section.

One of the main problems for designers is that different products often quote parameters obtained from different test methods and from implementation within different components. This makes it difficult to make objective comparisons of performance. This problem should reduce over time, as CE marking (**Section 30.2**) drives the standardisation of test methods.

30.5.1 Geosynthetic standards

European standards on geosynthetics are developed by the Technical Committee CEN/TC189, Geosynthetics. International standards are developed by a similar committee ISO/TC 221 Geosynthetics. The standards can be divided into those that apply to testing of geosynthetics and those that apply to product applications. The main application standards that are likely to be relevant to the use of geosynthetics in SuDS are summarised in **Table 30.4**. Application standards do not exist for all products (eg cellular confinement products), but this does not prevent their use.

The product standards in **Table 30.4** do not specify minimum requirements for properties, as these will be related to the site specific application. However, they do identify which tests are required as a minimum for particular applications. These are summarised in **Tables 30.5 and 30.6, Section 30.5.2**.

Example specifications for geosynthetics are provided by the International Geosynthetics Society (2006).

TABLE 30.4 Most relevant application standards for geosynthetics

Geosynthetic type	Relevant standards	Relevance to SuDS
Geotextiles	BS EN 13249:2014	Requirements for geotextiles used for filtration, separation or reinforcement in pavement construction will be relevant to pervious surfaces etc
	BS EN 13252:2014	Requirements for geotextiles used in drainage for filtration, separation or drainage (eg geocomposites used for drainage)
	BS EN 13253:2014	Some of the erosion control properties may be relevant to SuDS
Geosynthetic barriers	BS EN 13361:2013	Requirements for barriers on dam slopes including steep faces
	BS EN 13362:2013	Requirements for barriers lining channels

30.5.2 Laboratory testing of geosynthetics

Laboratory tests on geosynthetics can be divided into two classes:

- index tests
- performance tests

Index tests measure properties that can be compared to the specification for a product, and help assess variability between batches and compare different products. They cannot normally be used in design calculations. Index tests include thickness, density and weight, tensile strength (measured using narrow strip samples) and tear strength. They may be surrogates for other properties and can give an indication of likely behaviour.

Performance tests are carried out to determine properties that can be used directly in design calculations, such as wide strip tensile strength, interface friction, pore opening size and permeability. Where necessary, the tests should be undertaken using site-specific test conditions.

The properties in **Table 30.5** have to be declared by manufacturers in accordance with the European application standards discussed in **Section 30.5.1**. **Table 30.5** identifies which test methods should be used.

Other properties that are not mandatory include determining the thickness of a geotextile (BS EN ISO 9863-1:2005). This measurement is often necessary to allow the specification of a suitable geotextile for a particular application.

For geomembranes and geocomposite clay liners used in SuDS as waterproof liners, results for the tests in **Table 30.6** should be declared, and the test methods used should also be stated. The table is based on the application standard for canals, as this is considered to be most similar to the use of barriers in SuDS (rather than reservoirs and dams).

TABLE 30.5 Laboratory test methods for geotextiles

Property	Test method	Function				
		Filtration	Drainage	Reinforcement	Separation	Protection
Tensile strength	BS EN ISO 10319	✓	✓	✓	✓	✓
Elongation (at break)	BS EN ISO 10319		✓	✓		✓
Static puncture (CBR) resistance	BS EN ISO 12236			✓	✓	
Protection efficiency of geotextiles in contact with geosynthetic barriers	BS EN 13719					✓
Dynamic perforation resistance	BS EN ISO 13433	✓	✓	✓		✓
Water permeability (perpendicular to the plane)	BS EN ISO 11058	✓				
Characteristic opening size	BS EN ISO 12956	✓				
Water flow capacity (in the plane)	BS EN ISO 12958		✓			
Durability (to be assessed in accordance with guidelines specified in annex to the standards applicability of test methods dependent on materials and conditions of use)						
Resistance to weathering (UV)	BS EN 12224	✓	✓	✓	✓	✓
Resistance to oxidation	BS EN ISO 13438	✓	✓	✓	✓	✓
Microbiological resistance	BS EN 12225	✓	✓	✓	✓	✓
Resistance to liquids	BS EN 14030	✓	✓	✓	✓	✓

Note

See references at the end of this chapter for details of all of these standards.

TABLE 30.6 Test methods for geosynthetic barriers

Property	Type of barrier		
	Polymeric geosynthetic barrier	Bituminous geosynthetic barrier	Geocomposite clay geosynthetic barrier
Water permeability (liquid tightness)	BS EN 14150		BS EN 16416
Tensile strength	BS EN ISO 527-1 BS EN ISO 527-3 BS EN ISO 527-4 or BS EN 12311-2	BS EN 12311-1	BS EN ISO 10319
Static puncture (CBR) resistance	BS EN ISO 12236		
Durability (to be assessed in accordance with guidelines specified in annex to the standards applicability of test methods dependent on materials and conditions of use)			
Resistance to weathering (UV)	BS EN 12224		
Resistance to oxidation	BS EN 14575		
Environmental stress cracking	BS EN 14576	–	BS EN 14576

Note

See references at the end of this chapter for details of all of these standards.

30.5.3 Geotextiles as filtration and separation layers

The use of geotextiles as filters in SuDS may be required to achieve the following scenarios:

1. filter silt from the runoff within a system (eg when placed as an upper layer within a permeable pavement construction)
2. support the surrounding soil
3. provide a separation layer (eg to prevent finer soils washing into an underlying open void, such as a pipe or tank, or coarser drainage layers)
4. a combination of the above (eg the geotextile around a soakaway will support the surrounding soil and stop it collapsing into voids in the tank wall or any coarse aggregate backfill and also filter silt from water running out of the tank).

Geotextile filters may occasionally be required to act as a filter for groundwater draining into the SuDS to prevent soil fines being washed inwards, although this would be an exceptional design scenario.

The main design requirements are set out in **Table 30.7**.

Geotextiles can be manufactured as woven or non-woven materials. Woven geotextiles tend to have relatively few openings of relatively large size, whereas non-woven geotextiles tend to have many small openings and are, therefore, more suitable for filtration applications. Non-woven geotextiles also offer superior rates of perpendicular flow compared to woven geotextiles, unless woven geotextiles are made with deliberately large openings.

TABLE 30.7 Geotextile design requirements

Property	Design requirements
Permeability	The geotextile should have sufficient permeability to allow water to pass through it at the required rate. In SuDS design for scenarios 1, 2 and 4 (above) permeability should be considered the most important requirement.
Clogging prevention	The geotextile should retain the required silt or soil particle size without clogging. Normally there should be no need to filter soil particles, because groundwater should not be flowing into the SuDS, and the geotextile should simply be supporting soil in the unsaturated zone to prevent it collapsing into the SuDS. Note: There are various filter criteria used to assess the use of geotextiles as filters in other applications. These are explained by Giroud (2000). Clogging of a geotextile is caused by the retention of particles inside the fabric. A similar effect occurs by blinding, where particles block individual openings on the upstream side of the fabric. Geotextiles provide filtration where the geotextile is in good contact with a soil mass and the water flows in steady state in one direction through the soil and then through the textile into a void of some type. The steady flow and the soil structure ensure that only a minimal quantity of soil particles is moved towards the textile in an initial four-week period, thereafter the flow is only water. The textile is chosen with sufficient perpendicular permeability and an opening size such that the fine and medium soil particles can pass through the pores within the textile, but the larger particles in the soil cannot. The soil structure ensures that the medium and fine soil particles are held back within the soil and do not move towards the textile after an initial "flush". In that way, the textile has a very slight drop in performance initially, but thereafter is not subjected to any more soil particles over the rest of its design life. Geotextiles have been proven to work for an acceptable design life in filtration. There have been many equations developed based on this theory. Each equation has its own interpretation of how to match the soil particle size to the geotextile pore size. These filter criteria can be used in scenario 3 above, but are not applicable to any of the other scenarios.

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TABLE 30.7 Geotextile design requirements

Property	Design requirements
Clogging prevention	The classic Terzaghi stone filter and Giroud geotextile filter principles assume steady flow of water through the soil and the geotextile. Soil particle movement is limited and consequently a relatively long design life of the filter is attained. Conversely, when silt-laden water is continuously presented onto a geotextile, silt particles will accumulate on the geotextile, leading to reduced permeability and a relatively short, finite design life. The smaller the opening size and the greater the volume of runoff that is filtered, the shorter the design life will be. There is also less risk of premature failure if the perpendicular permeability of the silt-laden geotextile is less than the design flows. Comparison of the silt size in runoff with the opening size of a geotextile can help designers judge the likely rate of clogging in geotextiles used to filter silt from runoff (scenario 1), although the variation in grading of suspended solids in runoff should be recognised and eventually any geotextile for this application will clog.
Strength and durability	The geotextile should be sufficiently strong and durable to withstand the forces applied to it (eg within a permeable pavement construction, the geotextile can be subject to tearing and puncturing due to the forces transmitted from vehicles braking and turning, and the point loads particularly from very angular aggregates). This requires an assessment of the puncture and tearing forces on the geotextile.

30.5.4 Geomembranes and geocomposite clay liners used as waterproof barriers

Barrier types and performance requirements

There are many different types of barriers manufactured from various materials that prevent the movement of water. The European application standards BS EN 13361:2013 and BS EN 13362:2013 define three different types of barrier:

- polymeric geosynthetic barriers – plastic sheets such as polyethylene, PVC and polypropylene that are usually referred to as geomembranes
- bituminous geosynthetic barriers
- geocomposite clay geosynthetic barriers – a sandwich of bentonite clay between two geotextiles – commonly known as geocomposite clay liners (GCLs).

All the different materials have their own design considerations, and some will be more suitable than others for a given application. The prevention of water leakage from SuDS components is the primary purpose for any geomembrane or GCL. Most membranes, even very thin ones, will have sufficiently low permeability to contain water in a SuDS component if the material is intact and has been completely sealed during installation. However, with thinner and less durable membranes, leakage is likely to occur (**Box 30.1**), so reducing the risk of leakage tends to be the primary concern, rather than material permeability.

Leakage can occur due to poor field or factory seaming, or damage caused during or after installation. The main concerns in choosing a geomembrane barrier are:

- design and detailing to avoid tensile stresses in the membrane as far as possible
- construction quality control to minimise the risk of damage
- specification of membranes that have good resistance to puncturing and tearing (or the associated specification of geotextiles to protect thinner membranes) to minimise the risk of damage during and after construction.

Geosynthetic barriers and especially geomembranes should be installed by experienced and suitably qualified staff. The British Geomembrane Association (BGA) has an installer accreditation scheme approved by the Environment Agency and The Welding Institute (TWI) <**http://tinyurl.com/qzmdpna**>.

It is important that all joints and seams are visually inspected and tested on site to ensure that they meet the required standard. The main places where leaks are likely to occur is around penetrations, such as where a pipe passes through the material (eg where a pipe passes into a lined tank).

GCLs are generally used in combination with an existing clay barrier or in combination with a geomembrane in applications in which a significant water head is maintained. GCLs are not recommended for use on their own around geocellular tanks. However, where they are used under shallow SuDS water components, they may be suitable on their own (eg to prevent significant infiltration from a swale with a low head of water).

BOX 30.1 Geomembranes and construction

A critical property of any waterproof barrier is its ability to survive the construction process intact and in a good condition, so as to reduce the subsequent permeation of water to acceptable levels. The key physical parameters of barriers to be considered are:

- the material it is manufactured from
- its physical properties (tensile strength, puncture resistance, tear resistance)
- its permeability.

Thickness also becomes a key parameter, if joints of polymeric barriers are welded – see Mallett *et al* (2014). Protection of barriers during construction may be required to ensure that they have retained their integrity.

Particular care is required in specifying membranes below permeable pavements where the coarse-graded aggregate is located directly on the membrane. Thin membranes less than 0.5 mm thick are not likely to survive in this situation without holes occurring.

Design considerations

Key issues to be considered for any barrier system are set out in **Table 30.8**, together with the appropriate design approaches.

TABLE 30.8 Design considerations for waterproof barriers in SuDS

Design consideration	Design approach for the application of waterproof barriers in SuDS
Slope stability	For most SuDS applications, slopes should be low, which will minimise the risk of instability, but where geomembranes and geotextiles are to be laid on slopes, a stability assessment should be undertaken by a suitably qualified geotechnical engineer or engineering geologist.
Tree root penetration	If the system is well constructed and does not leak and nearby trees have sufficient and suitable soil around the roots, then root penetration through geomembranes should not be a problem. Risk of tree root penetration can be minimised by locating tanks outside the rooting area of trees or, where this cannot be achieved, by providing root barriers to protect membranes.
Temperature effects (thermal stresses in polymeric membranes and freeze/thaw in GCLs) and UV light	Geomembranes used in SuDS should normally not be exposed at ground level and will be covered by soil or aggregate. Temperature effects can be minimised by ensuring an adequate thickness of covering soil. The thickness required will depend on the local climate. However, experience with green roofs has shown that even a thin covering of soil (150 mm or greater) can improve the lifespan of waterproofing barriers significantly by protecting them from extreme changes in temperature and the associated stresses, as well as from UV light (Edge *et al*, 2007).
Drying and wetting effects for GCLs	Geocomposite clay liners include a layer of bentonite that has to be hydrated to form the barrier to water. If the GCL dries out, the bentonite shrinks and cracks. However, the bentonite will swell again on rehydration when it comes into contact with water, so there should not be any significant effect. Most GCL manufacturers should have test data to show that the GCLs can selfheal, if they dry out and are rehydrated.

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TABLE 30.8 Design considerations for waterproof barriers in SuDS

<table>
<tr><th>Design consideration</th><th>Design approach for the application of waterproof barriers in SuDS</th></tr>
<tr><td rowspan="3">Watertight seams</td><td>All barriers need to be joined together to be fully watertight. For polymeric membranes, this should be achieved by welding the sheets together. Taped joints are not suitable for water-retaining applications, and the conditions of installation for SuDS mean that it is unlikely that a taped joint can be formed effectively. The main reason for this is that an even pressure has to be applied over the whole joint area, and an even and firm substrate is required below the membrane to achieve this. This is not likely to be present in most SuDS installations.

Effective forming of taped seams requires firm, even support to allow pressure to be applied with a roller.

The thickness of a membrane is very important when considering welding. Membranes less than 1 mm thick are much more prone to welding problems, especially of burning holes in the material (Schiers, 2009). However, thinner membranes of the same material tend to be more flexible and are easier to install, especially around geocellular tanks, where corners and other details are much more prevalent. Flexible membranes can also be prefabricated into panels in the factory. There is, therefore, a trade-off between robustness and the risk of defects due to difficulty of installation. If a membrane less than 1 mm thick is to be welded, it should be shown, by testing a trial welded joint, that it can be joined in a satisfactory manner (known as a seam test).</td></tr>
<tr><td>
Figure 30.2 Applying pressure to a taped joint to ensure adequate sealing (courtesy EPG Limited)</td></tr>
<tr><td>Where GCLs are used, they cannot (and do not need to) be welded together. They rely on good overlap and pressure on them to maintain an effective seal. The minimum overlap should be 300 mm, with sufficient soil cover to hold the GCL sheets in place. The geotextile panels can also be welded to minimise the risk of movement between adjacent panels.</td></tr>
<tr><td>Chemical</td><td>Geomembranes and GCLs are resistant to a wide range of chemicals, but there are some that are known to have a deleterious effect. Chemicals that affect GCLs do not usually affect membranes and vice versa, hence they are often used in combination. A thorough assessment of the potential exposure of geomembranes to chemicals and the likely effects, should be made, especially where they are used in contaminated sites or in sites where the runoff could be highly polluted, such as industrial sites.</td></tr>
</table>

Design verification plans

Where geosynthetic barriers are to be included as part of a SuDS, a verification plan should be provided as part of the design. The plan should outline the required performance verification activities (inspection and testing), the relevant personnel to be used and the types of records to be collected. The greater the reliance that is placed on the barrier, the greater the verification requirements. The plan would need to be flexible enough to respond to any changes to the design of the SuDS (either during the design process or during construction), but it should be sufficiently well defined to enable all parties to appreciate the scope of these activities and how they could affect, or be affected by, the construction. The plan should identify its objectives (ie why it is being carried out), the method(s) to be employed, the critical parts of the barrier and the potential (or perceived) areas of weakness that would need particular attention during verification.

The verification should be carried out by a third party that is independent of the installer of the barrier (**Box 30.2**). The Environment Agency has provided clear advice with respect to the level of independence and verification in relation to work on landfill sites (EA, 2010).

BOX 30.2 **Independent verification**

The Environment Agency recommends that conflicts of interest in verification should be avoided in the field of contaminated land verification (EA, 2010). The same philosophy should apply to verification of geomembranes in SuDS.

A contractor or membrane supplier certifying their own work or product is considered to be a conflict of interest and is not good practice. If verification is carried out by the same company (or related company) that carried out the installation, then the process, the results and the report should be audited by an independent consultant (Mallett *et al,* 2014).

Verification test methods for geomembranes after construction

After installation of a geomembrane in SuDS, it may require testing to show that the joints are fully sealed and that the main body of material has not been damaged and does not have any holes or tears. Test methods that have been, or could be, used on geosynthetic barriers in SuDS can be subdivided into two main elements:

1 testing of seams

- pressurised air channel tests to ASTM D5820-95 and D7177-05
- mechanical point stress test to ASTM D4437-08
- air lance test to ASTM D4437-08.

2 testing of (large) areas of flat gas membrane installed in its final position

- tracer gas testing
- dielectric porosity testing to ASTM D4787-13 and ASTM D7240-06
- smoke testing.

Further information on these tests is provided in Mallett *et al* (2014).

30.5.5 Use of geotextiles to protect geomembranes from damage

The purpose of protection geotextiles is to prevent damage to geosynthetic barriers (primarily polymeric barriers). They may be placed above and/or below a membrane, depending on the design of the barrier system and the underlying/overlying materials. In some applications, geosynthetic barriers can be exposed to significant puncture and

Figure 30.3 Installation of pond liner with protection fleece (courtesy Stormwater Management)

shear forces (eg below permeable pavements and wrapping geocellular tanks, where a minimum 2 mm thick and minimum 300 g/m^2 weight geotextile should be specified).

As discussed above the geotextile should be sufficiently strong and durable to withstand the forces applied to it, which requires an assessment of the puncture and tearing forces on the geotextile. Protection is normally achieved by using thicker non-woven geotextiles, although GCLs have also been used as protection layers.

30.5.6 Geocomposites used for drainage layers or in trenches

Geocomposites are a form of geosynthetic that is made by creating a single component from two or more elements (eg a drainage core and a geotextile). An example of a geocomposite used for drainage is shown in **Figure 30.4**.

Figure 30.4 Geocomposite drainage layer (courtesy Stormwater Management Ltd and Geosynthetics Ltd)

The main requirements for the geotextile will be the same as for any other filtration application as described in **Section 30.5.3**. The drainage core will need sufficient in-plane permeability to convey the required water flows, and this can be tested in accordance with BS EN ISO 12958:2010 at an applied normal stress that reflects what will occur in service. It is particularly important that the correct boundary conditions are assessed for in-plane flow. BS EN ISO 12958 expects soft plattens to simulate soil/stone backfill, but has the option of hard plattens to simulate geomembrane. Soft platten results are often much lower than hard platten results.

The geotextile will also need to be sufficiently permeable to allow water to enter the core, and this should be determined in accordance with BS EN ISO 11058:2010. A specification for geocomposites to be used in drainage is provided in the HA (2009a).

Geocomposites have been used to collect water from the sub-base of permeable pavements (laid vertically and connected to pipes). They have also been laid horizontally below the sub-base to enhance the drainage. In this situation they are subject to traffic loads and the strength and deflection

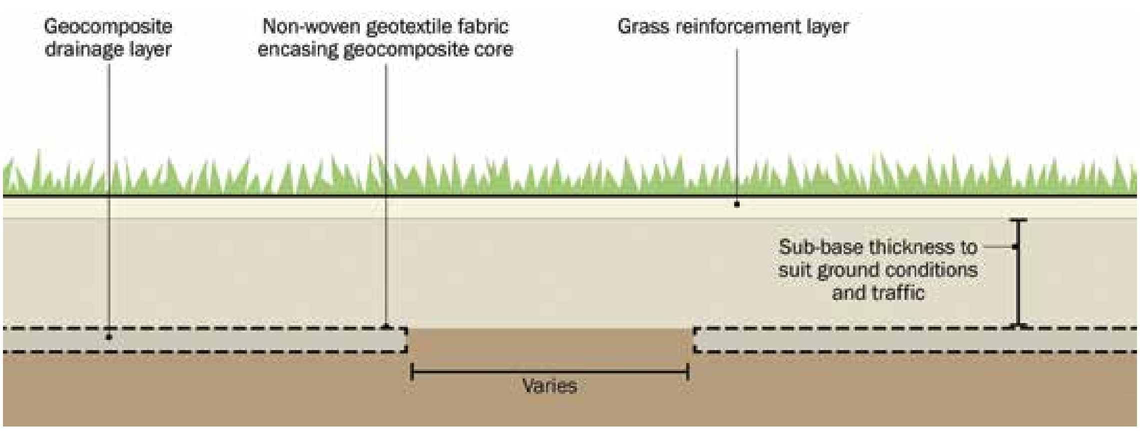

Figure 30.5 Geocomposite drainage strips used below permeable paving

characteristics will have to be assessed to ensure that the geocomposite can support the loads and the pavement materials can tolerate the deflections that occur in the composite under traffic loadings.

30.5.7 Geosynthetics and natural materials used for erosion control

Erosion control is an important consideration in SuDS design and construction. It is especially important immediately after construction when vegetation is not fully established. Materials used as erosion control blankets in SuDS include jute netting, coir blankets and synthetic products. They allow the quick establishment of vegetation on slopes and channels subject to erosion from water action and can also slow down the velocity of water flowing across a surface (**Chapter 29**).

All erosion control blankets work by providing some mechanical anchorage to top soil/sediments and seeds. The choice of a suitable specification will depend on whether the erosion protection is required to be temporary or permanent.

Erosion control blankets usually comprise biodegradable mesh-like products, which will disappear in one to five seasons, depending on the material, and hence are suitable for the establishment of low-growing vegetation. Jute and similar products will degrade in one or two growing season and are usually designed to help establish grass/turf in locations where there is not likely to be high water flows. The longer-lasting products, such as those made of coir (woven coconut fibre mesh), can be used for lining of swales and ponds where slightly longer-term abrasion/erosion protection is required to ensure that vegetation can become fully established. If the erosion control blankets are required to operate over the full service life of the SuDS, then the materials used should not be biodegradable, and a synthetic mat should be used. Non-biodegradable products are synthetic materials and usually comprise 3D random fibre mats or honeycomb webs. Some synthetic products are also photodegradable, and the same principles apply: the product should last for the full service life of the SuDS.

Erosion control blankets can be supplied on their own or can be preplanted.

The important parameters to consider when specifying erosion control matting are:

- weight – gives some indication of durability
- yarn thickness and number of threads – gives some indication of durability and strength
- open area – affects water permeability and soil retention properties
- yarn quality – affects how long the mesh takes to degrade, its water retention and its flexibility
- function when installed – will it be planted up for eventual self-sustainability and cohesion with new developing root systems (in which case a biodegradable material is suitable) or will it need to act as erosion control in the longer term, such as for topsoil retention on slopes (in which case the product should not degrade over the service life of the SuDS)?

There are no UK or European standards relating to the use of erosion control matting. BS EN 13253:2014 does not cover surface erosion, where the geotextile or geotextile-related product is located at the surface. Examples of erosion control products are shown in **Figures 30.6 to 30.8**.

Figure 30.6 Example of topsoil retention on slope using cellular confinement (courtesy EPG Limited)

Figure 30.7 Example of coir matting for a swale (courtesy Stormwater Management)

Figure 30.8 Example of synthetic matting (courtesy ABG)

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Image courtesy JPP Consulting

31 CONSTRUCTION

Contents

Chapter 31 Construction

This chapter provides general good practice guidance on the construction of SuDS schemes.

- *Construction checklists are provided in Appendix B.*
- *Guidance on construction for specific types of SuDS component can be found in Chapters 11–23.*

31.1 CONSTRUCTION BEST PRACTICE FOR SUDS

The construction of SuDS usually only requires the use of standard civil engineering and landscaping operations such as excavation, filling, grading, pipe-laying, chamber construction, topsoiling, seeding and planting. These operations are specified in various standard construction documents, such as WRc (2011). However, there are some specific process and programming considerations required for their application to SuDS construction, as described in **Box 31.1**.

The same attention to detail (including tolerances) for SuDS construction is required as for other forms of construction. Contractors will become familiar with the specific issues and construction techniques as the use of SuDS becomes more widespread.

BOX 31.1 General construction issues relating to SuDS

1 Programming

The programming of SuDS construction needs to be considered at all stages of the site construction process. Subsurface piped drainage networks are usually one of the first facilities to be constructed on a site. For SuDS, although the form of the drainage will be constructed during the earthworks phase, the final construction should not take place until the end of the development programme, unless adequate provision is made to remove any silt that is deposited during construction operations and to refurbish any areas that have been subject to over-compaction.

Method statements and pre-construction site planning operations will form an essential part of pre-construction activities to ensure successful completion of the SuDS.

The construction of swales, basins and ponds at an early stage in the construction can assist in managing runoff and help settle out the high volumes of sediments created during construction. However, complete reinstatement of these components will be required once construction is finished. The contract is likely to stipulate establishment of vegetation and sediment removal sometime after site works have been completed and before the start of the maintenance period.

2 Pollution and sediment control

Runoff from a construction site should not be allowed to enter SuDS or flow off site unless it has been allowed for in the design and specification. Construction runoff is heavily laden with sediment, which can clog infiltration systems, build up in storage systems and pollute receiving waters. Certain SuDS components should not be used to

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BOX 31.1 **General construction issues relating to SuDS**

manage construction runoff, for example pervious surfaces. No traffic should be allowed to run on pervious surface components if it is likely to introduce sediment onto the pavement surface from dusty or muddy areas, or result in over-compaction. One way of protecting permeable sub-base construction, so that it can be used for construction traffic, is to cover it with a layer of asphalt concrete that is cored through before laying the blocks to make it permeable (**Chapter 20**).

3 Access and storage areas

Traditional car parking and other paved areas are usually constructed (or partially constructed) during the initial stages of the development, and then used as access roads and storage areas. If pervious surfaces are proposed, pavement construction should be carried out at the end of the development programme, unless adequate protection is provided to preventing clogging or blinding.

Ease of access for the construction of other components needs to be considered at the design and programming stage.

4 Skills

The contractor and all relevant operatives should have a general understanding of how SuDS work and the purpose of the specific SuDS components being used on a site, to ensure that appropriate construction practice and component protection is used. "Toolbox talks" for workers are a particularly effective way of increasing awareness of appropriate construction of SuDS.

5 Infiltration system protection

If SuDS components do not allow infiltration, the use of hardcore for structural purposes below the level of any liner or other impermeable layer may be acceptable. However, the use of hardcore is not advised if infiltration is intended, due to the high proportion of fines generally present in such fill material. Total exclusion zones may be required for construction traffic over infiltration surfaces to prevent compaction and other damage to the ground that will affect the infiltration performance. This may include complete isolation from runoff during construction if the component is located at a low point on the site. Proof rolling of pavement formations is not recommended as this will compact the ground and reduce the infiltration rate, so other methods of identifying soft spots should be used.

6 Landscaping

Good landscape construction practices are fundamental to SuDS construction. As SuDS are normally surface systems, attention to detail and aesthetics should be given a high priority. The seasonal and physical requirements of planting and the requirements for establishing vegetation and preventing soil erosion should be given careful consideration. Appropriately skilled and experienced operatives are required with an understanding of all aspects of vegetation establishment. Adjacent ground levels to components should be designed to prevent any overland sediment wash-off during high intensity rainfall events, or groundwater seepage during particularly wet periods. Settlement of soils should also be taken into consideration. Further guidance is provided in **Chapter 29**.

7 Erosion control

Before runoff is allowed to flow through vegetated SuDS, they should be fully stabilised by planting or temporary erosion protection. This will prevent erosion of the sides and base or the clogging of downstream components.

8 Construction and handover inspection

Provision should be made in the construction contract for inspections at key stages, and on completion of construction, to ensure that the system has been constructed in accordance with the approved design and specification. As-constructed drawings should be produced and an as-constructed survey undertaken to ensure that design levels have been achieved. A construction checklist is provided in **Appendix B**.

9 Specifications and bills of quantities

Designers should highlight particular matters associated with the above points that are likely to impact the operation and performance of specific SuDS components. The type of specification and/or bills of quantities will depend upon the form of construction contract being used for the specific project.

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31.2 CONSTRUCTION PROGRAMMING FOR SUDS

Effective construction programming for SuDS is very important in order to:

- protect the receiving environment from runoff during construction
- protect each SuDS component from damage during construction
- protect the natural infiltration characteristics of the site soils and subsoils
- deliver a surface water management system where runoff is conveyed and stored, as designed, without causing unacceptable erosion, channelling or sedimentation
- promote the healthy establishment of required vegetation and habitats
- facilitate and accommodate appropriate inspections required by adoption bodies during the construction period.

Construction activities do not usually occur in a specified linear sequence, and programmes will vary, owing to weather and other unpredictable factors. Construction should be co-ordinated with other development activities, so that all work can take place in an orderly manner and on programme. Experience shows that careful project programming improves efficiency, reduces cost and lowers the potential for erosion and sedimentation problems.

Construction access is normally the first land-disturbing activity. Care should be exercised so as not to damage infiltration surfaces or valuable trees or to disturb designated buffer zones or natural hydrological features that are to be protected for the site. Access should be designed to use existing gaps in hedges where possible. Trees should be protected following the guidance in BS 5837:2012. Activities that could compact the root zone should not be allowed in the designated tree root protection zone and barriers should be installed to prevent access to these areas.

Sediment basins and traps should be installed before any major site earthworks/groundworks take place. Further sediment traps and silt fences should be installed as earthworks/groundworks progress, to keep sediment contained on site at appropriate locations.

Runoff control measures should be used in conjunction with sediment traps to divert water around planned earthworks areas and to remove silt. Surface water runoff from upstream should be diverted around areas to be disturbed before any earthworks/groundworks operations. Any perimeter drains should be installed with stable outfalls before opening major areas up for development. Any additional facilities needed for runoff control should be installed as earthworks/groundworks take place.

The main runoff conveyance system with inlet and outlet protection measures is often installed early, and used to convey surface water runoff through the development site without creating gullies or channels. Inlet protection for surface water drains should be installed as soon as the drain is functional, to trap sediment on site in shallow pools and to allow flood flows to safely enter the surface water drainage system. Outlet protection should be installed at the same time as the conveyance system to prevent damage to the receiving water body.

Clearing and earthworks/groundworks should only be started when adequate erosion and sediment control measures are in place. Once a development area is cleared, earthworks should follow immediately, so that protective ground cover can be re-established quickly. Areas should not be left bare and exposed for extended periods. Adjoining areas planned for development or those that are to be used for borrow and disposal should be left undisturbed as long as possible, to serve as natural buffer zones. Runoff control is essential during the earthworks/groundworks periods. Temporary diversions, slope drains and inlet and outlet protection installed in a timely manner can be very effective in controlling erosion during this critical period of development.

Surface stabilisation measures should be applied to completed areas, channels, ditches and other disturbed areas after the land is cleared and profiled. Any disturbed area where active construction will not take place for more than 60 working days should be stabilised by temporary seeding and/or mulching or by other suitable means. Permanent stabilisation measures should be installed as soon as possible after final profiling. Temporary seeding and/or mulching may be necessary during extreme weather conditions, with permanent vegetation measures delayed until a more suitable installation time.

Construction of pervious surfaces, landscape works and final stabilisation should be left to the later stages of construction. All disturbed areas should have permanent stabilisation measures applied. Unstable sediment should be removed from sediment basins and traps and, if possible, incorporated into the topsoil, not just spread on the surface. All temporary structures should be removed after the area above has been properly stabilised. Borrow and disposal areas should be permanently vegetated or otherwise stabilised. Infiltration and filtration surfaces that have been protected during construction should be rehabilitated (if required), exposed and stabilised.

Upon completion of construction (including vegetation establishment where this is part of the SuDS or associated with runoff surfaces contributing inflows to the SuDS), there is likely to be a commissioning period in which the permanent SuDS are made "live", ie flow is diverted into them. If permanent SuDS components have been used wholly or in part to drain the site or as other forms of temporary works, such as roads or storage areas, there may be rehabilitation works required to reconstitute or restore them to their design condition. Construction programming should aim to minimise the need for rehabilitation works. Once the permanent components have been demonstrated to work as envisaged, then temporary drainage and sediment and erosion control measures can be carefully dismantled, so as not to generate sediment loadings to downstream systems.

In programming construction work, all land-disturbing activities necessary to complete the proposed project should be outlined and then all practices needed to control erosion and sedimentation on the site should be listed in sequence. Features requiring particular attention during planning a construction project are: site access; storage of materials; interim site drainage during the construction phase; and protection of surfaces (such as to prevent compaction – **Figures 31.1 and 31.2**).

Figure 31.1 Inadvertent compaction of subgrade below pervious surface construction intended to infiltrate water to ground. Compaction will reduce the infiltration rate (courtesy EPG Limited)

Figure 31.2 Absence of erosion protection before establishment of vegetation (courtesy EPG Limited)

Small sites with no unused space can be difficult to programme if extensive permeable/infiltrating surfaces are part of the design. **Figure 31.3** shows the construction of concrete block permeable paving on a small infill development of a few houses. The construction of the paving has been left until the end of the project when there will be no or limited work that can result in damage or clogging of the pavement. It will be difficult to avoid compaction of the soils at formation on such a site. If the pavement was intended to allow infiltration to the soil below, it may be necessary to rotovate or scarify the formation to rehabilitate the infiltration capacity before constructing the surface (or design the pavement with an outfall to a sewer or watercourse). Another method of protecting the formation is to leave a sacrificial 200 mm or so layer of soil in place until final excavation to formation levels just before the pavement is constructed.

Figure 31.3 Concrete block permeable paving being constructed at the end of the project (courtesy EPG Limited)

31.3 CONSTRUCTION METHOD STATEMENTS

The purpose of a construction method statement is to:

- formalise who is responsible for completing the work
- set out the approach, processes and programme proposed for constructing and stabilising the SuDS (so that those with delivery responsibility understand what is to be done, how and why)
- identify any unusual items or methods of working that are required.

Every job is different and every method statement should be site specific. Most of the information included in standard method statements for health and safety and general management of the construction process will be acceptable, with the addition of information specific to the SuDS. This means that there will be negligible extra work required to prepare the SuDS construction method statement. The main requirements for a SuDS construction method statement are:

- details of the nature of the work to be completed
- site plans and full scheme drawings, where these are required to support the method of approach
- consents and reinstatement requirements
- access points and details
- any site-specific ecological issues or features that require protection and/or consideration
- any likely water quality issues resulting from the SuDS construction
- the proposed strategy for sediment control and site drainage during the construction of the development, where this impacts on the SuDS proposed for the site; it should identify any potential impacts on the final performance of the drainage system and any necessary protection measures (or remedial works such as silt removal at the end of construction of the development)

- measures to prevent inadvertent access across the completed or partially completed SuDS; for example the area above a geocellular tank that has not been designed to support heavy traffic, or a completed infiltration basin that cannot be trafficked, should be surrounded by a physical barrier; vehicle access routes should be clearly marked (this is usually required for safety reasons as well).

Contractors and developers are familiar with preparing construction method statements for a wide variety of purposes, not least to manage health and safety and contractual risks on construction sites.

In terms of health and safety, the method statement details a safe system of work. It identifies the hazards that may arise during construction and the measures that are to be taken to ensure that the hazards do not pose an unacceptable risk to workers and the public.

Method statements for SuDS are necessary because many people in the construction industry are not familiar with the specific requirements for constructing SuDS and some of the requirements are contrary to accepted practice in some fields (for example, the requirement for a drop from hard surfaces to grassed areas where water is flowing off an edge is the opposite to normal practice, which is to raise the turf level above the hard surface).

It is also important to understand the impact of other construction activities on the SuDS (for example, once permeable sub-base is laid, it cannot be used as a construction route or platform, unless it is protected from siltation and loading damage. The permeable sub-base in the parking bays in **Figure 31.4** has been protected by a temporary cover of hardcore over a geotextile separator. The road surface has been left lower than the edging (before final surfacing which is normal practice) and this also prevents silt-laden runoff draining onto the parking areas.

Figure 31.4 Temporary surface over permeable sub-base in parking bays (geotextile and hardcore) (courtesy EPG Limited)

The construction method statement should be used by the drainage adoption body to plan the appropriate construction inspection regime that will enable them to be satisfied that the system has been constructed in accordance with the design. Guidance on delivery of an appropriate construction assessment process is set out in **Appendix B**.

The implementation of a comprehensive quality assurance (QA) regime is fundamental to the achievement of a minimum standard of workmanship. It is generally accepted that a high proportion of the perceived failures of SuDS are as a direct result of either poor quality workmanship at the installation stage or damage during construction. Construction method statements are a crucial part of reducing construction risks.

Correct construction of SuDS is of equal importance to design if the systems are to be successfully implemented, and the key to this is conveying information to site staff (management and operatives). They should be made aware of how the SuDS scheme operates, the design requirements and how their actions on site can affect the final performance of the scheme. It is important to talk to people on site, especially operatives, and to ensure that all subcontractors and their staff are also involved in this process. Site staff and operatives should also be taught how to install critical items, if necessary, for example where geotextiles and geomembranes are to be placed in the construction. Clogging, blinding or over-compaction of permeable surfaces due to unconsidered construction activities are common risks. The preparation and dissemination of appropriately detailed method statements emphasising the differences from traditional construction activities is seen as an important communication channel, to be used in conjunction with toolbox talks and direct briefings to operatives. To assist in these processes a construction site handbook is available (Woods Ballard *et al,* 2007)

31.4 EROSION CONTROL

31.4.1 Factors influencing erosion during construction

Any activity that disturbs the natural soil and vegetation has the potential to increase erosion, because bare loose soil is easily moved by wind or water.

Factors affecting the erosion potential of any site include soil type, geology, vegetative cover, topography, climate and land use. Physical properties of soils, such as particle size, cohesiveness, and density, affect its erodibility. Loose silt and sand-sized particles are more susceptible to erosion than clay soils. Coarser soils are less susceptible to wind erosion, but are often found on steeper slopes that are subject to water erosion. When surface cover and soil structure are disturbed, the soil's erodibility potential increases. Construction activities disrupt the soil structure and its vegetative cover.

Vegetation plays an important role in controlling erosion. Roots bind soil particles together, and the leaves or blades of grass reduce raindrop impact forces on the soil. Grass litter and other ground cover traps rain, which allows infiltration and reduces runoff velocity. Also carefully sited vegetation can steer pedestrian movement away from vulnerable areas to prevent erosion.

Vegetation reduces wind velocities at the ground surface and provides a rougher surface that will trap particles moving along the ground. Once vegetation is removed, erosion can proceed unchecked.

The factors that influence land erosion by water are:

- runoff velocity
- runoff volume
- soil type
- vegetation cover
- machinery and plant
- de-watering outlets.

Land erosion is caused by the runoff being of sufficient velocity to strip fine silts and soils. **Table 31.1** shows how different type of soils and vegetation coverage can affect the velocity needed to cause erosion.

TABLE 31.1 Maximum allowable velocities based on soil type

Soil type	Maximum allowable velocity m/s	
	Seeded	Turfed
Sand	0.6	0.9
Silt loam, sandy loam, loamy sand	0.6	0.9
Silty clay loam, sandy clay loam	0.75	1.2
Clay, clay loam, sandy clay, silty clay	0.9	1.5

31.4.2 Erosion control procedures

The objective of erosion control is to limit the amount and rate of erosion occurring on disturbed areas. Erosion of the surface of SuDS components will reduce their effectiveness and add to the silt load to downstream components and/or receiving water bodies. Design requirements to help prevent erosion, such as limiting water velocities, are discussed in the individual technical SuDS component chapters.

Erosion controls are surface treatments that stabilise soil exposed by excavation or earthworks/groundworks.

Erosion control activities that should be considered during construction include the following:

1. Conduct all land disturbing activities in a manner that effectively reduces accelerated soil erosion and reduces sediment movement and deposition off-site.
2. Schedule construction activities to minimise the total amount of soil exposed at any given time, to reduce the period of accelerated soil erosion.
3. Establish temporary or permanent cover on areas that have been disturbed as soon as possible after final grading is completed.
4. Design and construct all temporary or permanent facilities for the conveyance of water around, through or from the disturbed area to limit the flow of water to non-erosive velocities.
5. Remove sediment caused by accelerated soil erosion from surface runoff water before it leaves the site.
6. Stabilise the areas of land disturbance with permanent vegetative cover as quickly as possible.

Permanent or temporary soil surface stabilisation should be considered for application to disturbed areas and soil stockpiles as soon as possible after final profile is reached on any portion of the site. Soil surface stabilisation should also be considered for disturbed areas that may not be at final profile but will remain undisturbed for more than 60 days.

A viable vegetative cover should be established within one year on all disturbed areas and soil stockpiles not otherwise permanently stabilised. Vegetation is not considered established until a ground cover is achieved that is sufficiently mature to control soil erosion and can survive moderate runoff events.

Roads and other hardstandings should be covered as early as possible with the appropriate bound layer where this is specified as part of the pavement.

If stockpiles are located within 30 m of a watercourse, sediment controls, such as a diversion ditch or silt fence, should be provided.

Properties and roadways adjacent to a construction site should be protected from eroded sediment being transported onto them. Whenever construction vehicles enter onto paved roads, provisions should be made to prevent the transport of sediment (mud and dirt) by those vehicles. Whenever sediment is transported onto a public road, regardless of the size of the site, the roads should be cleaned at least daily or as required to keep the roads clear of mud.

Temporary diversion ditches should be considered above disturbed areas and may be discharged to a permanent or temporary channel. Diversion ditches located mid-slope on a disturbed area or at the base of a disturbed area should discharge to a sediment trap or basin.

31.4.3 Erosion protection techniques

Impermeable area runoff should not be allowed to flow directly over areas of exposed ground. Runoff should either be intercepted by a sewer system or gravel trench, or suitable erosion protection techniques should be used. Approaches include:

- **vegetation** – reinforces the soil due to the binding effects of the root structure. It helps protect areas downstream by the friction effect of the vegetation decreasing the runoff velocity.
- **geotextiles, geocellular confinement and erosion control fabrics** – reinforce the soil structure reducing the potential for particle stripping (**Chapter 30**).
- **reinforced grass** – consists of plastic moulds which are placed in the soil and allow grass to grow though them. Reinforced grass has the benefit of offering early erosion protection as well as protecting the grass areas from traffic loading.
- **gravel trenches** – can be located upstream of exposed land. They intercept runoff that then enters a perforated pipe system to an outfall or infiltrates into the ground. However, because they are usually sacrificial in nature, these systems can be relatively expensive to install for short durations. If such a system is being installed as part of the final SuDS solution for a site, it should not be used for construction runoff, because heavy sediment loads during construction will reduce its design life.
- **flat sites or slack gradients** – will help reduce the velocity of the runoff.

Further guidance is provided in Hewlett *et al* (1996) and Coppin and Richards (2007).

31.5 SEDIMENT CONTROL

31.5.1 Principles of sediment control

During a rainfall event, runoff normally builds up rapidly to a peak and then diminishes. Because the amount of sediment conveyed in runoff is dependent upon the velocity and volume of that runoff, sediment tends to be deposited as runoff rates decrease. The deposited sediments may be resuspended with subsequent runoff – in this way, sediments are moved progressively downstream.

By effectively controlling erosion (**Section 31.4**), the supply of sediment on a site can be significantly reduced, but sediment trapping and management will still be required for residual loadings.

31.5.2 Sediment control techniques

Sediment controls used during construction include straw bale barriers, geotextile silt fences and sediment basins. The type of sediment control system to be used depends on the catchment area and the site slope. Proprietary treatment systems have also been used to control construction stage sediment in surface water drainage systems. **Table 31.2** summarises the recommended maximum catchment areas, slope lengths and slopes for straw bale barriers and geotextile silt fences.

TABLE 31.2 Sediment control system design criteria

	Allowable maximum limits		
Sediment control facility	Drainage catchment area (hectares)	Drainage catchment slope length (m)	Drainage catchment slope gradient
Straw bale barrier or silt fence	0.6–1.2 per 100 linear metres	50	1:2 (50%)

All runoff leaving a disturbed area should pass through a sediment control system before it exits the site and is conveyed downstream.

Straw bale barriers or silt fences may be used for small sites. When the catchment area is greater than that specified in the table, runoff should be collected in diversion ditches and routed through temporary sediment basins.

Straw bales can be placed at the base of a slope to act as a sediment barrier. Straw bales are temporary in nature and may only perform for a period of weeks or months. Proper installation and maintenance is necessary to ensure their performance.

A silt fence is made of a woven synthetic material, geotextile, and acts to filter runoff. Silt fencing can be placed as a temporary barrier along the contour at the base of a disturbed area. The material is durable and will last for more than one season if properly installed and maintained. Silt fencing is not intended to be used as a perimeter fence or in areas of concentrated flow paths. If concentrated flow conditions exist, a more robust filter should be considered.

Silt barriers can also be temporarily installed in or around any road gullies of partially constructed roads to prevent sediment movement into downstream drainage systems.

Where some sediment loads are still likely to be transported into the construction drainage system, sediment basins, proprietary systems or other facilities should be designed to trap it and facilitate its easy removal. Consideration should be given to the risk of sediment resuspension during storm events, and appropriate risk management measures should be put in place. Suitable sediment removal regimes should be identified to ensure that the storage capacity of the component is not exceeded. Where there is a risk of sediment contamination, it may be necessary to line the basin to prevent any risks of contamination of underlying soils and/or groundwater. Where basins, proprietary treatment systems or other methods are to be included as permanent features in the SuDS design, they will require complete clean-out (and rehabilitation if necessary) once construction is complete.

31.6 POLLUTION CONTROL

31.6.1 Pollution prevention

Detailed guidance on prevention of pollution during construction is provided in Masters-Williams *et al* (2001) and also in the pollution prevention guidelines produced by the EA *et al* (2012).

The main requirements are to control pollution loads from surface water runoff and pumped water from construction sites to ensure that risks to the environment are minimised. The safe storage of materials and fuels is also important so that if spills occur they are contained (by the use of berms, check ditches or other containment techniques) and do not cause mix with runoff and thus increase pollution risks.

Before mobilisation, the construction site layout should be planned so as to fully consider issues such as the location of stockpiles, fuel stores, storage areas, waste disposal, refuelling points and wash down areas. These should be located in areas where they are least likely to affect receiving water bodies (including groundwater). Planning should also address subjects such as the diversion of watercourses, prevention of upstream runoff entering the site and the design of haul roads, including the use of road bridges over watercourses to stop vehicles fording streams and rivers.

An environmental pollution protection plan should also be put in place. The plan should include:

- location of foul drainage disposal routes
- location of surface water systems that discharge into watercourses
- requirements for discharge and abstraction licences
- location of spillage kits
- an action plan in the event of an environmental incident (including a list of relevant telephone contact numbers).

31.6.2 Construction pollution sources and controls

Sediment

Sediment is one of the major sources of construction site pollution. The following list indicates a number of sources and the measures that can be taken to help prevent pollution:

- **Excavated ground and exposed ground** – The effect of having no vegetation and being recently disturbed allows for relatively low velocity runoff to erode the surface. To help prevent the pollution from entering a watercourse, silt fences, hay bales or stilling ponds should be placed downstream. To limit the volume of runoff reaching the exposed ground, runoff diversion or interception devices should be placed upstream.
- **Stockpiles** – The effects of erosion on a stockpile will depend on the type of material being stored. Fine sand and topsoil stockpiles will be eroded far more readily than heavy granular materials. Stockpiles should be located away from a watercourse or site drainage system. Protective coverings will help prevent runoff stripping the stockpile.
- **Plant and wheel washing** – Plant and wheel washing should take place in designated locations. The area should be tanked and should not be allowed to discharge into a watercourse or infiltrate groundwater, as the wastewater from these devices is highly contaminated with silts, sands and hydrocarbons. Some proprietary vehicle washing systems offer a recycling facility, which filters and settles solids, with the effluent being pumped back into the system. The solid waste materials from this process need to be treated as contaminated waste due to the high hydrocarbon content.
- **Haul roads** – The runoff from haul roads contains a large amount of suspended solids as well as hydrocarbons. Haul roads should be designed so that the length is kept to a minimum, while still serving its purpose. The gradient should be shallow to prevent increasing runoff velocity and, if possible, bunds and/or discrete ditches should be constructed to intercept the runoff. Haul roads should be sprayed regularly to keep down dust. If any section of a haul road is hard surfaced, then it should be swept on a regular basis to prevent the accumulation of dust and mud.
- **Disturbance of riverbeds or banks** – Excavation of riverbanks or beds can generate silty water, as the excavated and exposed material is washed downstream. The amount of such excavation needs to be limited and, if undertaken, the water area downstream needs to be protected by booms. For larger projects, consideration should be given to diverting the river while such excavations take place.
- **De-watering operations** – Groundwater discharge due to excavation activity is likely to be heavily polluted with suspended solids and should not be discharged directly into a watercourse. To help reduce the amount of suspended solids within the runoff a number of techniques can be adopted:
  - passing the discharge water over a grass area, but the discharge velocity has to be monitored and kept sufficiently low to promote settlement
  - passing the discharge water though a temporary gravel strip
  - controlled use of skips and/or tanks to act as stilling basins
  - controlled use of stilling ponds.

Oils and hydrocarbons

The use of oils and hydrocarbons on construction sites creates an inherent risk of leakages and spillages, which could potentially lead to pollution incidents. **Table 31.3** details the potential sources of hydrocarbon pollution.

Simple measures can be taken to prevent oil and hydrocarbons becoming entrained in surface runoff, such as:

- appropriate maintenance of machinery and plant
- drip trays
- regular checking of machinery and plant for oil leaks
- correct storage facilities

- checking for signs of wear and tear on tanks
- care with specific procedures when refuelling
- designated areas for refuelling
- emergence spill kit located need refuelling area
- regular emptying of bunds
- tanks located in secure areas to stop vandalism
- booms installed on watercourses.

TABLE 31.3 Sources of hydrocarbon pollution on a construction site

Sources	Potential problem initiators
Storage tanks	▪ leaking valves ▪ leaking pipe work ▪ corrosion ▪ frost damage ▪ vandalism ▪ leaking bund
General operation and maintenance	▪ removal of waste ▪ refuelling ▪ leaking pumps, browsers, generators, plants, machinery ▪ disposal of waste oil
Accidents/incidents	▪ spillages (greatest risk at refuelling) ▪ overturning (drums and buckets) ▪ mechanical failure eg rupture of pipes ▪ inadequate bunded area ▪ vandalism

31.7 SUDS CONSTRUCTION INSPECTIONS

Inspections are required at frequent intervals during SuDS construction and also once construction is complete and the system is operating as designed. Inspections are required to ensure that each element of the system is constructed correctly, and that design assumptions and criteria are not invalidated, for example, by the construction methods used, by changes made on site or by variations in ground conditions. The form of the inspection will depend upon the type of construction contract used, but an independent inspection regime by the approval body or designer is preferred to any contractor self-certification approach. A construction checklist is provided in **Appendix B**.

These inspections should be undertaken as necessary, but as a minimum would generally be expected to include:

1. pre-excavation inspection to ensure that construction runoff is being adequately dealt with on site and will not cause clogging of the SuDS
2. inspections of excavations for ponds, infiltration devices, swales etc
3. inspections of infiltration surfaces before overlay by any construction
4. inspections during laying of any pipework
5. inspections and testing during the placing of earthworks, pavement or filter materials
6. inspection and level check of the prepared SuDS component before planting begins

7 inspection of completed SuDS after surfacing or planting

8 final inspection before handover, to ensure that all construction silt has been removed, the final construction is in accordance with the design and there are no visible defects.

The contractor installing the SuDS scheme should be made fully aware of the requirement for inspections, to avoid work being undertaken that cannot be validated. Final inspection should take place at the end of the maintenance period as defined in the contract (typically 1 year).

On completion of construction, the approving body or designer should provide a verification report that discusses the inspections, the reasons for any variations made to the design, any non-compliances that are identified and how they were rectified. During the first year of operation there may be a need for monitoring to identify any modifications that may be required to optimise performance, if this has been required and stated as part of the design. The scope of the monitoring will be site specific and depends on the sensitivity of the design and the consequences if the SuDS does not perform as expected.

31.8 SUMMARY

In summary the following issues should be considered by those responsible for the design, programming and construction of SuDS.

Designers

- avoid using infiltration or pervious surfaces in area likely be required for construction traffic
- design to allow drainage of site during construction
- dissemination of information to contractors to ensure SuDS are constructed correctly
- design for ease of construction.

Site managers

- effective programming
- prepare construction method statements
- dissemination of information to supervisors and operatives to ensure that SuDS are constructed correctly
- arrange construction access so that it will not adversely affect SuDS performance
- arrange for effective silt and pollution control during construction
- arrange for prompt planting and establishment of landscaped SuDS features
- ensure that appropriate erosion control is in place
- arrange for construction checks and inspections at appropriate times.

Construction supervisors and operatives

- understand requirements for construction and ask for information from site manager if not clear
- do not compact areas for infiltration
- ensure that required erosion, pollution and silt control is in place before starting work
- minimise exposed areas of bare soil
- avoid placing construction materials on completed SuDS (eg topsoil on pervious surfaces).

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Image courtesy Simon Bunn

32 OPERATION AND MAINTENANCE

Contents

Chapter 32

Operation and maintenance

This chapter discusses general good practice for operation and maintenance activities, and the types of documents that can be developed to define the requirements at a particular site.

- ▶ *Specific maintenance requirements for each type of SuDS component are listed in detail towards the end of each of the SuDS component chapters (Chapters 11–23).*
- ▶ *Chapter 29 provides further detail on landscape design (including planting) for ease of maintenance.*
- ▶ *Chapter 33 provides guidance on waste management, including waste resulting from maintenance.*

32.1 INTRODUCTION

Many SuDS components are visible on the surface, form part of the overall site landscape and include a range of habitats. Depending on the design, maintenance regimes need to take account of the wider landscape context of amenity and biodiversity, as well as drainage requirements. The maintenance activities required to deliver the desired amenity, for example, may exceed those required to deliver the designed water quantity and water quality performance. In such cases, this needs to be recognised by those responsible for delivering and maintaining that functionality. Where SuDS components are hard surfaces or below ground, the maintenance will generally be based on engineering requirements.

For the purpose of this manual, maintenance refers to:

- inspections required to identify performance issues and plan appropriate maintenance needs
- operation and maintenance of the drainage system
- landscape management
- waste management associated with contaminated silt and other waste materials resulting from maintenance.

All maintenance will need to take the protection of habitats and associated ecology into account (**Chapter 6**). Maintenance regimes should be regularly assessed (eg once per year) to make sure that the approach is still meeting the drainage, landscape and any other objectives. This may result in changes to the maintenance of a feature or area. For example, more frequent vegetation management may be identified where vegetation growth is obstructing highway sight lines.

The function of the surface water management system should be understood by those responsible for maintenance, regardless of whether individual components are below ground or on the surface. When problems occur in vegetated components on the surface, they may be obvious and can be remedied using standard landscape or engineering practices. However, this is not always the case – particularly with more complex systems such as bioretention systems and pervious surfaces. If any system (whether above or below ground) is properly designed, monitored and maintained, performance deterioration can usually be minimised.

Ease of maintenance and access is therefore a necessary and important consideration of SuDS design (not least as part of CDM requirements to ensure that maintenance can be undertaken safely). Sufficient thought should be given to the likely required maintenance over the design life of the SuDS and its funding during the feasibility and planning stages of a scheme (**Chapter 35**). In particular, the following requirements should be given full consideration:

- maintenance access – ensuring appropriate and permanent access to all points in the system where future maintenance may be required
- forebays and/or appropriate pre-treatment systems to help trap sediment
- appropriate provision for temporary drainage, if required, during sediment management or other maintenance activities
- the availability of storage and disposal areas for green waste, such as grass cuttings and organic sediments.

Appropriate legal agreements between adoption and maintenance organisations that define maintenance responsibilities are presented in Shaffer *et al* (2004). Maintenance Plans will often be required as a condition of planning for the site. For example, many buildings are required to achieve a high BREEAM rating and a landscape management plan (LMP) is a mandatory requirement to achieve this. Planning authorities will include this in a planning condition.

The LMP can also form a useful tool for public or client engagement with SuDS and help them to understand the wider benefits of the system. They can include the provision for ecological re-survey, tree inspection and works and information about how the system delivers multiple benefits.

32.2 OPERATION AND MAINTENANCE MANUAL

Those responsible for SuDS within a development (owner, tenant, local authority, water company etc) should ideally be provided with an operation and maintenance manual by the designer. This could be part of the documentation provided under CDM (part of the health and safety file).

If the user of the system is not responsible for maintenance, then it is important to ensure that they know when the SuDS is not functioning correctly and who to contact if an issue arises, such as a blockage at a SuDS pond seen by a householder on a housing estate or a tenant on an industrial estate.

The operation and maintenance manual should be succinct and easy to use and should include the following:

- location of all SuDS components on the site
- brief summary of the design intent, how the SuDS components work, their purpose and potential performance risks
- depth of silt that will trigger requirement for removal
- visual indicators that will trigger maintenance
- depth of oil in separators etc that will trigger removal
- maintenance requirements (ie the Maintenance Plan) and a maintenance record pro forma
- explanation of the objectives of the maintenance proposed and potential implications of not meeting those objectives (it may be useful to split this into planted and hard elements, for clarity)
- identification of areas where certain activities are prohibited (eg stockpiling materials on pervious surfaces)
- an action plan for dealing with accidental spillages of pollutants

- advice on what to do if alterations are to be made to a development or if service companies need to undertake excavations or other similar works that could affect the SuDS
- details of whom to contact in the event that pollution is seen in the system or if it is not working correctly.

The operation and maintenance manual should also include brief details of the design concepts and performance criteria for the scheme and how the owner or operator should ensure that any works undertaken on a development do not compromise this. For example, householders should be made aware that surface water drainage is connected to soakaways, and be given full details and maintenance obligations for any rainwater harvesting systems in the property. This education is part of the wider community engagement process that is vital to the successful uptake of SuDS (**Chapter 34**). The operation and maintenance manual may also include the LMP.

It is important on industrial estates to clearly identify to everyone which areas drain to SuDS and which to foul sewer. For example, gullies and manhole covers could be colour coded or marked. Owner and tenants should be made aware of what is allowed to drain to the SuDS. Similarly, it is a good idea to use interpretation boards, for example at a pond on a housing estate, to increase householders' awareness of the purpose and benefits of the SuDS and to encourage them not to put polluting substances down the surface water drainage system (**Chapter 27**).

32.3 LEVEL OF OPERATION AND MAINTENANCE

There are many factors that will influence the type and frequency of maintenance required for a SuDS component or scheme at any particular site, including:

- the type of SuDS components
- the size of the contributing catchment in relation to the area of the SuDS components (this will affect the likely sediment loading rates and potential for erosion etc)
- the land use associated with the contributing catchment (this will affect the likely build-up of contamination)
- the level of continuing construction within the contributing catchment
- the SuDS planting scheme
- the habitat types that have been created as part of the scheme and how they are anticipated to evolve into a mature landscape
- the amenity and visual requirements of the area.

The demands on the SuDS component or scheme to perform a particular aesthetic function may be a key driver, with high frequencies of grass cutting and/or other vegetation management often being required for appearance and amenity value rather than for functional reasons. Specific habitats may dictate the time of year that is suitable for particular activities to be undertaken (eg reed cutting), and/or the extent of the system that should be subject to certain activities at any one time (eg sediment removal). Plants and trees tend to require different periodic management techniques as they mature. This is particularly relevant to coppice areas and woodland, or indeed shrub and herbaceous planting, some of which may require renewal after 10 years or so, depending on the planting and its purpose.

The maintenance regime of a site also needs to consider the response to extreme pollution events. A response action plan should be developed and communicated to all those involved in the operation of a site, so that if a spillage occurs it can be prevented from causing pollution to receiving waters.

It is recommended that SuDS are not handed over to those responsible for maintenance until upstream construction has ceased, the contributing catchment has stabilised, and any necessary rehabilitation of downstream components has been undertaken by the developer/contractor. However, if maintenance agreements have to be put in place in advance of this time, and the level of construction activity in the contributing catchment is still high, maintenance specifications should be prepared that take account of high sediment accumulation rates and the increased risks of potential spillages.

32.4 OPERATION AND MAINTENANCE ACTIVITY CATEGORIES

Maintenance activities can be broadly defined as:

1. regular maintenance (including inspections) – **Section 32.6**
2. occasional maintenance – **Section 32.7**
3. remedial maintenance – **Section 32.8**.

There may also be initial one-off requirements sometimes referred to as “establishment maintenance”, particularly for planting (eg weeding and watering). Regular maintenance consists of basic tasks carried out to a frequent and predictable schedule, including inspections/monitoring, silt or oil removal if required more frequently than once per year, vegetation management, sweeping of surfaces and litter and debris removal.

Occasional maintenance comprises tasks that are likely to be required periodically, but on a much less frequent and predictable basis than the regular tasks (eg sediment removal or filter replacement). **Table 32.1** summarises the likely maintenance activities required for each SuDS component, and guidance on specific maintenance activities is given in the following sections.

Remedial maintenance describes the intermittent tasks that may be required to rectify faults associated with the system, although the likelihood of faults can be minimised by good design, construction and regular maintenance activities. Where remedial work is found to be necessary, it is likely to be due to site-specific characteristics or unforeseen events, and so timings are difficult to predict. Remedial maintenance can comprise activities such as:

- inlet and outlet repairs
- erosion repairs
- reinstatement or realignment of edgings, barriers, rip-rap or other erosion control
- infiltration surface rehabilitation
- replacement of blocked filter materials/fabrics
- construction stage sediment removal (although this activity should have been undertaken before the start of the maintenance contract)
- system rehabilitation immediately following a pollution event.

It is important to note that these remedial activities will not be required for all systems, but for the purpose of estimating whole life maintenance costs, a contingency sum of 15–20% should be added to the annual regular and occasional maintenance costs to cover the risk of these activities being required.

TABLE 32.1 Typical key SuDS components operation and maintenance activities (for full specifications, see Chapters 11–23)

Operation and maintenance activity	SuDS component												
	Pond	Wetland	Detention basin	Infiltration basin	Soakaway	Infiltration trench	Filter drain	Modular storage	Pervious pavement	Swale/bioretention/trees	Filter strip	Green roofs	Proprietary treatment systems
Regular maintenance													
Inspection	■	■	■	■	■	■	■	■	■	■	■	■	■
Litter and debris removal	■	■	■	■	□	■	■	□	■	■	■		□
Grass cutting	■	■	■	■	□	■	■	□	□	■	■		
Weed and invasive plant control	□	□	□	□		□	□		□		□	■	
Shrub management (including pruning)	□	□	□	□					□	□	□		
Shoreline vegetation management	■	■	□										
Aquatic vegetation management	■	■	□										
Occasional maintenance													
Sediment management[1]	■	■	■	■	■	■	■	■	■	■	■		■
Vegetation replacement	□	□	□	□						□	□	■	
Vacuum sweeping and brushing									■				
Remedial maintenance													
Structure rehabilitation /repair	□	□	□	□	□	□	□	□	□	□	□	□	
Infiltration surface reconditioning				□	□	□	□		□	□	□		

Key

■ will be required

□ may be required

Notes

1 Sediment should be collected and managed in pre-treatment systems, upstream of the main device.

32.5 HEALTH AND SAFETY

To comply with the Construction (Design and Management) Regulations (CDM) 2015, designers must assess all foreseeable risks during construction and maintenance and the design must minimise them by the following (in order of preference):

- avoid
- reduce
- identify and mitigate residual risks.

Designers must also make contractors and others aware of risks, in the health and safety file, which is a record of the key health and safety risks that will need to be managed during future maintenance work. For example, the file for a SuDS pond should contain information on the collection of hazardous compounds in the sediment, so that maintenance contractors are aware of it and can take appropriate precautions. During construction, the residual risks must be identified and an action plan developed to deal with them safely (the health and safety plan and site rules).

All those responsible for maintenance should take appropriate health and safety precautions for all activities (including lone working, if relevant), and risk assessments should always be undertaken. Guidance on generic health and safety principles is provided in **Chapter 36**.

32.6 REGULAR MAINTENANCE

32.6.1 Inspections and reporting

An initial pre-handover inspection of the scheme is required, to ensure that it has been constructed as designed (**Chapter 31**).

Regular inspections of SuDS will then:

1. help determine optimum future maintenance activities
2. help establish ongoing hydraulic, water quality, amenity and biodiversity performance of the system
3. allow identification of potential performance failures, such as blockage, reduced infiltration and poor water quality resulting from lack of maintenance.

Maintenance of SuDS is carried out by a range of people, which can include school caretakers, highway authorities, facilities management companies and landscape contractors. Pervious surfaces and proprietary systems will most likely be managed by people familiar with highway or drainage maintenance. Landscaped systems will be managed by the landscape contractor, although connecting pipework may be managed by others.

Where the maintenance of a system is carried out by those responsible for the wider landscaped area, the inspections can generally be undertaken during routine site visits (eg for grass cutting, leaf collection and/or litter collection) for little extra cost, although there may need to be dedicated visits during some winter months.

The staff doing the landscape maintenance should have appropriate experience of SuDS maintenance and should be capable of keeping sufficiently detailed records of any inspections. If staff do not have appropriate experience, then specific inspection visits will be necessary.

Those with overall responsibility for the drainage system may not be responsible for maintenance of the wider landscape and in those circumstances specific inspection visits may also be required at a suitable interval.

Specific visits will also be required if the system includes proprietary treatment systems (**Chapter 14**).

Whichever arrangements are made, the inspections should be recorded, and the records saved for future reference (**Section 32.10 and Appendix B**).

During the first year of operation of all types of SuDS, inspections should usually be carried out at least monthly (and after significant storm events) to ensure that the system is functioning as designed and that no damage is evident.

Typical routine inspection questions that will indicate when occasional or remedial maintenance activities are required for any type of system include:

- Are inlets or outlets blocked?
- Does any part of the system appear to be leaking (especially ponds and wetlands)?
- Is the vegetation healthy?

- Is there evidence of poor water quality (eg algae, oils, milky froth, odour, unusual colourings)?
- Is there evidence of sediment build-up beyond the designer's stated limits?
- Is there visual evidence of oil accumulation?
- Is there evidence of ponding above an infiltration surface?
- Is there any evidence of structural damage that requires repair?
- Are there areas of erosion or channelling over vegetated surfaces?
- Is there any visual evidence of regular or unplanned over-topping of banks?

For large sites, it is recommended that an annual maintenance report and record should be prepared by the maintenance contractor, which should be retained with the operation and maintenance manual (**Section 32.2**). The report should provide the following information:

- observations resulting from inspections
- measured sediment depths (where appropriate)
- monitoring results, if flow or water quality monitoring is undertaken
- confirmation that any penstocks or valves are free and working correctly
- maintenance and operation activities undertaken during the year
- recommendations for inspection and maintenance programme for the following year.

As with any paved area, safety inspections of pervious surfaces will be necessary for tripping hazards. If pervious surfaces are to be used in a shopping centre car park or high footfall area, these should be inspected monthly as a minimum, and repairs made as necessary through the lifetime of the surface. This would apply to any type of surface. Guidance is provided by the Road Liaison Group (2005).

32.6.2 Litter and debris removal

Litter and debris removal is an integral part of SuDS maintenance for surface features, in order to reduce the risks of inlet and outlet blockages, to retain amenity value and to minimise pollution risks. High litter removal frequencies may be required where aesthetics are a major driver, for example on residential sites or at high profile commercial or retail parks. Litter removal is less of an issue for engineered or underground systems, such as pervious surfaces, filter drains and proprietary systems and will normally form part of routine open space maintenance.

32.6.3 Grass cutting

It is recommended that the grass cutting regime around SuDS components is carefully specified to maximise the performance of the SuDS and meet visual requirements. In general, allowing grass to grow tends to enhance water quality performance. Short grass around a wet system, such as a pond or wetland, provides an ideal habitat for nuisance wildlife species such as geese, but allowing the grass to grow is an effective means of discouraging them. Grass around wet pond or wetland systems should not be cut to the edge of the permanent water in order to deter large birds and to reduce the risks of nutrients associated with grass cuttings falling into the water.

Figure 32.1 Grass cuttings

Grass cutting is an activity primarily undertaken to enhance the perceived aesthetics of the facility. The frequency of cutting will tend to depend on surrounding land uses, and public requirements. Grass cutting should be done as infrequently as possible, recognising the aesthetic preferences of local residents and other landscape management activities required at the site. Visibility around highways also needs to be considered. Grass around inlet and outlet infrastructure should be strimmed closely to reduce risks to system performance. If a manicured, parkland effect is required, then cutting will need to be undertaken more regularly than for meadow type grass areas, the latter aiming to maximise habitat and biodiversity potential. The impact of grass cutting on soil compaction should also be considered. The landscape management plan will usually identify the mowing regimes required in different areas or zones.

Guidance on designing a site to ease maintenance, such as limiting the slope of grassed areas, is provided in **Chapter 29**.

In the past there have been recommendations that keeping grass short in filter strips and swales prevents the grass lodging over (ie being pushed over and flattened by the flow of water) and improves pollution removal. However, the risk of pollution removal being compromised is now considered to be minimal and there is no reason for a blanket requirement to keep grass short in all swales and filter strips.

32.6.4 Weed and invasive plant control

Weeds are generally defined as vegetation types that are unwanted in a particular area. For SuDS, weeds can include:

- alien or invasive species (ie plants that are particularly aggressive, non-native species), the spread of which is generally undesirable
- plants that negatively affect the technical performance or amenity/biodiversity value of the system.

In some places, weeding has to be done by hand to prevent the destruction of surrounding vegetation (hand weeding should generally only be required during the first year, during plant establishment). However, mowing can be an effective weed management measure for grassed areas. Where the use of herbicides and pesticides is permitted (**Chapter 29**), this should be limited, where possible, to the establishment period, as the benefits of rapid sward/plant cover development are likely to outweigh any potential resulting water quality deterioration. The use of fertilisers should also be limited or prohibited, to minimise nutrient loadings, which are damaging to water bodies.

Specific advice on weed control for green roofs, filter drains and pervious pavements is provided in **Chapters 12, 16 and 20** respectively.

32.6.5 Shrub management

Shrubs may be densely planted and may mature very rapidly over the first year. They are likely to require weeding at the base, especially during the first year or two, to ensure that they get enough water, and mulching to retain water in the soils where possible. Bark mulch around shrubs should not be used, as it floats and clogs outlets. Pruning shrubs can result in a denser structure and better lateral growth, which may be desirable in SuDS.

32.6.6 Aquatic and shoreline vegetation management

Aquatic plant aftercare in the first 1–3 years may be required to ensure establishment of planted vegetation and to control nuisance weeds and invasive plants. Once it is established, the build-up of dead vegetation from previous seasons should be removed at convenient intervals (eg every 3 years and at the end of landscape contract periods) in order to reduce organic silt accumulation. Emergent vegetation may need to be harvested every 2–10 years in order to maintain flood attenuation volumes, optimise water quality treatment potential and ensure fresh growth. Where the density of vegetation is high, annual removal may be required. Care should be taken to avoid disturbance to nesting birds during the breeding season and habitats of target species (eg great crested newt and water voles) at critical times. The window for carrying out maintenance to achieve this is towards the end of the growing season (typically September and October, but this will vary with species). As vegetation matures, plant height may need to be reviewed with respect to any health and safety framework or strategy such as if it blocks necessary sightlines to an open water feature.

Where emergent vegetation is managed, up to 25% can be removed by cutting at 100 mm above soil level using shearing action machinery. Up to 25% of submerged vegetation can be cut and raked out at any one time, using approved rakes, grabs or other techniques, depending on whether clay or waterproof membranes are present. Aquatic vegetation arisings should be stacked close to the water's edge for 48 hours to de-water it and allow wildlife to return to the SuDS feature. They should then be removed to wildlife piles, compost heaps or off site before decomposition, rotting or damage to existing vegetation can occur.

Algae removal may be undertaken for aesthetic purposes during the first 3–5 years of a pond/wetland's life. The growth of algae, which is considered by some to be visually intrusive, is encouraged by nutrients introduced into the water body. This situation should settle down once upstream construction activities are complete.

32.6.7 Sweeping pervious surfaces

Pervious surfaces need to be regularly cleaned of silt and other sediments to preserve their infiltration capacity. Typically this will be required no more than once per year and often less, where inspections indicate that it is not required. Refer to **Chapter 20** for details of this process.

32.6.8 Oil removal and cleaning or replacing filters in proprietary systems

Oil removal from proprietary treatment systems should be undertaken at intervals recommended by the manufacturer. This will depend on the catchment characteristics. On small sites with a low pollution hazard, small amounts of oil may be removed by skimming, using small van-mounted equipment. This is relatively inexpensive. Those serving larger, more heavily polluted catchments may require tankers to remove the accumulated oil.

Where proprietary systems use filters, they should be replaced or cleaned at the intervals recommended by the manufacturer. For example, the coalescing filters in an oil separator can require cleaning every 6 months if the runoff from the catchment has a high oil load (eg from a heavily used road).

32.7 OCCASIONAL MAINTENANCE

32.7.1 Sediment removal

To ensure the long-term performance of SuDS, the sediment that accumulates in treatment components should be removed periodically (whether landscaped or proprietary systems). The required frequency of sediment removal is dependent on many factors including:

- design of upstream drainage system
- type of system
- design silt storage volume
- size of upstream catchment in relation to surface area of SuDS component
- characteristics of upstream catchment area (eg land use, level of imperviousness, upstream construction activities, erosion control management and effectiveness of upstream pre-treatment).

Figure 32.2 De-silting (courtesy Bedford Group of Drainage Boards)

Sediment accumulation will typically be rapid for the entire construction period (including during the period of building, turfing and landscaping of all upstream development plots). Once a catchment is completely developed and all vegetation is well-established, sediment mobility (erosion) and accumulation is likely to drop significantly.

Detailed information on waste management (in particular with respect to sediment removal) is provided in **Chapter 33**.

For most small features, sediment can be removed either by hand or using small excavators. For any system that has a waterproof liner, the method of sediment removal should be chosen so there is minimal risk of damaging the liner.

For proprietary treatment systems, a suction tanker will be needed to remove the sediment. The size of tanker will depend on the scale of the proprietary system and its location. For small catchments using treatment channels, silt accumulation in the channel can often be removed with hand tools or a small suction tanker.

General sediment removal considerations

Sediment removal from SuDS systems should always be carried out such that no damage is caused to the SuDS, and impacts on ecological systems and aesthetic appearance are minimised. The appropriate method of sediment removal at a particular site will depend on the size of the SuDS component, the access, whether the sediments are submerged or lying on dry ground, the sediment properties, the design characteristics of the SuDS component, visual requirements and wildlife concerns and sediment depths.

For small source-control SuDS components where sediment volumes are likely to be small, it is usually appropriate to remove sediment using hand tools and appropriate protective equipment. Where components and associated sediment volumes are larger, or where the sediment has accumulated in a permanent water body, then mechanical equipment may be required.

In particular, it is recommended to do the following:

1. Establish how the structure is lined and avoid damage to clay puddle layers or waterproof membranes.
2. Undertake work between September and March to minimise impacts on receiving water bodies (high suspended solids can cause reduced dissolved oxygen levels, which causes particular problems during elevated summer temperatures). Where required, works may be restricted to September and October, in order to protect breeding or hibernating wildlife.
3. Where machinery or pumping is to be used, agree the sediment removal and management plan in advance with the environmental regulator.
4. Where machinery is used to excavate sediment, undertake the operation in dry weather when the surrounding ground is firm, and ideally operate from a hard surface.
5. Use machinery with an extending arm to avoid contact with edges, banks and other features within a minimum distance of 1 m from the edge. Use a bucket without teeth to avoid puncturing clay layers or waterproof membranes.
6. Secure consent for any de-watering operations with the environmental regulator, if required.

Specific requirements of different SuDS components are presented in subsequent sections. Individual SuDS component chapters should be referenced for further details.

Sediment removal from retention ponds

Ponds and wetlands may eventually accumulate sufficient sediment to impact on the storage capacity of the permanent pool. This loss of capacity can affect both the appearance and the pollution removal efficiency of the pond. The rate at which this occurs will depend on allowances made during storage capacity design. The loss in storage will occur more rapidly if the pond receives additional sediment input during the construction phase. The accumulation of sediment should be monitored and where it is significant and/or if the quality in the pond begins to deteriorate, sediment characterisation should be undertaken to establish the need and options for its removal.

Figure 32.3 Floating excavator working in small pond (courtesy Land & Water)

The following issues should be considered:

1 Regular partial sediment removal is most effective, but may not be economic. However, where possible, sediment should not be removed from more than 50% of the pond or wetland area at any one time.
2 Appropriate bankside working areas should be selected, and wetland and bankside habitats protected.
3 Sufficient vegetation should be retained to ensure rapid re-colonisation of damaged areas.
4 Ideally, sediment removal should remove only accumulated inorganic and organic sediment, but not wetland subsoil or topsoil layers. In practice, this can be difficult to achieve.

Specialist contractors should generally undertake sediment removal from ponds or wetlands. The types of machines capable of removing sediment from a pond will vary. It may be possible to drain the pond and employ a mini excavator or excavator with swamp tracks to excavate sediments from within the feature, or else an excavator may have to be deployed from the bank. Standard hydraulic excavators have limited reach, but are normally sufficient to deal with removal from small features within sites. For large ponds, a long-reach excavator may be required that can reach up to 25 m.

A further option that may occasionally be necessary is to use machinery on floating pontoons and/or barges. **Figure 32.2** shows a floating excavator working in water.

For safety reasons excavators cannot operate close to overhead power lines and they need a clear area to swing their bucket and dump spoil. This should be taken into account when assessing the access required for maintenance (eg if a pond is surrounded by trees or buildings).

If de-watering of ponds in advance of sediment extraction is feasible at a site, and assuming that the water body can be left drained for a reasonable period of time (ie a few weeks), then this can considerably reduce the volume of material to be extracted and that will require disposal, and will often allow some biodegradation of organic material.

De-watering can be undertaken by:

1 draining down the pond using the penstock or outlet valve (if included within the design)
2 pumping out the pond.

Both options require consideration of the environmental impact of the de-watering, especially with respect to downstream receiving waters, which could be a sewer, watercourse or other water body. In some cases, water pumped from ponds or settlement channels has to be tankered off site. Discharge to a watercourse or body is likely to require discharge consent from the environmental regulator. Consent from the sewerage undertaker will be required if the discharge is to a sewer, and large-scale de-watering may also require planning permission. Testing of the system water quality (for COD, BOD, suspended solids and metals – in consultation with the environmental regulator) may be required to demonstrate the likely risks to the local environment and this can be undertaken together with the sediment sampling.

The water may contain high concentrations of suspended solids that are either already in suspension or become entrained as a result of the pumping process. Adequate sediment control should therefore be provided before the pumped water is discharged. Once the pumped water is running clear then the sediment control devices may be bypassed as long as sediment is not reintroduced into the system. Appropriate sediment control systems include:

- temporary traps formed by constructing an earth embankment with a gravel filled outlet across a swale
- sediment basins (this can include the use of floodable fields)
- sumps (either constructed or mobile proprietary units)
- geotextile filters.

A dump truck with a watertight tailgate is likely to be required to remove the sediment from the site.

Sediment removal from detention basins

Dry basins accumulate sediment with time that will gradually reduce the storage capacity available and can in some cases also reduce sediment trapping efficiency. Also, sediment may tend to accumulate around the control device, which increases the risk that either the orifice may become clogged or that sediment may become re-entrained into the outflow. Where basins are amenity features, sediment accumulation is likely to be unsightly and reduce the amenity value of the component. Sediment accumulation should be monitored as part of the inspection regime for the surface water management system and appropriate frequencies determined for removal and disposal. Small volumes of sediment can usually be removed by landscape contractors using hand tools. Sediment excavation using front-end loaders or backhoes is simple, if appropriate access is available for the equipment. Sediment removal will usually damage the vegetation, and re-establishment may be required.

Sediment removal from filter strips and swales

Sediment accumulation should be monitored as part of the inspection regime for the surface water management system and appropriate frequencies determined for removal and disposal. Filter strips and swales will only accumulate very small volumes of sediment which can be removed by landscape contractors using hand tools at appropriate frequencies depending on the impact of the accumulation on the performance of the component in terms of hydraulics (eg sheet flow characteristics), water quality (eg vegetation cover) and amenity (eg visual).

Sediment removal from infiltration basins

Infiltration basins should always have source control, a pre-treatment or other sediment trapping system upstream. Even with low sediment loads, the system performance can still become significantly impaired in a relatively short space of time. The sediment deposits reduce the storage capacity and may also clog the surface soils. Dense vegetation can minimise the risk of surface clogging (**Chapter 13, Section 13.12**).

Methods of removing sediment from infiltration basins are different from detention basins. Removal should not start until the basin has dried out, at which point the top layer should then be removed using lightweight equipment, with care being taken not to unduly compact the basin surface. The remaining soil can then be scarified or tilled to restore the surface infiltration capacity (see **Chapter 13** for detail of these methods). Vegetated areas disturbed during sediment removal should be replanted or re-sown immediately to reduce the risk of erosion. Suitable erosion control should also be provided.

Sediment removal from proprietary systems

Proprietary systems should be cleaned out regularly to prevent re-entry of any residuals or pollutants into the downstream system. The frequency will depend on the site-specific pollutant load, but most suppliers/manufacturers recommend that cleaning operations should take place every 6 months. They can be cleaned by vacuum pumping which transfers a slurry of water and sediment to a tanker, or by adding chemicals to help solidify the residuals, which can then be removed using appropriate methods.

Maintenance of pervious pavement systems involves removing sediment from the pavement surface using vacuum sweeping. It is recommended that the pavement be vacuum swept once a year, and the collected sediments will require appropriate handling and disposal.

Sediment removal from filter drains

Filter drains will require occasional removal of the gravel infill which can be either cleaned and reused, or new material used as a replacement. The geotextile surrounds to the trench and to pipes may also require replacement at this time.

Small lengths would probably be cleaned using a small excavator to remove the material and replace it with clean. There are specialist companies that can clean long lengths of linear filter drain (eg alongside roads) using specialist machinery. The machinery can easily deal with single size material of 40 mm and Type B filter material (**Chapter 30**). It may require adapting, or the settings changed to deal with other infill materials. The machinery lifts the filter material from the trench, segregates and cleans it and then returns it to the trench. Typically the machines will clean the gravel to depths of 300 mm or exceptionally 600 mm.

Disposal of silt and debris that is removed is achieved via a belt which can discharge to a truck running alongside, or it can be deposited well back on the verge if permitted. The amount of spoil is usually in the order of 5–10 tonnes for every 100 m of drain cleaned to 300 mm depth.

32.7.2 Vegetation and plant replacement

Some replacement of plants may be required in the first 12 months after installation (ie the defects liability/rectification period), possibly after storm events. Dead or damaged plants should be removed and replaced, to restore the prescribed number of living plants per m^2. The responsibility for doing this should be made clear in the construction contract.

Inspection programmes should identify areas of filtration, or infiltration surfaces where vegetation growth is poor and likely to cause a reduced level of system performance. Such areas can then be rehabilitated, and plant growth repaired.

32.8 REMEDIAL MAINTENANCE

32.8.1 Structure rehabilitation and repair

The need for component rehabilitation (eg to remove clogged filters, geotextiles and gravels) will typically be 10–25 years, depending on the component design and factors such as the type of catchment and sediment load. The SuDS design should allow for vehicle access to undertake this work and consider how to implement such overhauls without causing major disruption to the functionality of the drainage system. For example, if geotextiles are used at a high level within a pervious surface, then reconstruction of the surface and bedding layer is all that is required if they become clogged, rather than reconstruction of the whole pavement depth.

Some form of rehabilitation is likely to be required at some point where component functionality relies on filtration through soils or aggregates. However, for many SuDS components, routine maintenance is sufficient.

Rehabilitation activities for each SuDS component are described in the individual component chapters. The requirements should be identified in the operation and maintenance manual.

32.8.2 Infiltration surface rehabilitation

Inspections should look for signs of infiltration surfaces becoming clogged, such as if water is standing for long periods on the surface or if it is flowing via an overflow channel and bypassing the basin. In the event that grassed surface permeability is unacceptably reduced, there are a number of landscape techniques that can be used to open the surface to encourage infiltration. Such activities are likely to be required in circumstances where silt has not been effectively managed upstream, or the infiltration surface has been compacted by foot traffic (eg if a basin is also used as a recreational area).

Scarifying to remove "thatch"

Thatch is a tightly intermingled organic layer of dead and living shoots, stems and roots, developing between the zone of green vegetation and the soil surface. Scarifying with tractor-drawn or self-propelled equipment to a depth of at least 50 mm breaks up silt deposits, removes dead grass and other organic matter and relieves compaction of the soil surface.

Spiking or tining the soil, using aerating equipment to encourage water percolation

This is particularly effective where a hollow tine machine is used, and sand is dressed in, and is best undertaken when the soil is moist (note: the removal and disposal of the dried cores will be necessary). Spiking or tining with tractor-drawn or self-propelled equipment penetrates and perforates soil layers to a depth of at least 100 mm (at 100 mm centres) and allows the entry of air, water, nutrients and top dressing materials.

Air pressure treatment

If the infiltration capacity has reduced due to compaction, it may be possible to rehabilitate it using air pressure treatment. This process breaks up subsoil layers by driving probes into the ground. The probe is connected to a high pressure gas source (typically nitrogen bottles) and a high pressure stream of gas is quickly introduced into the soil. This causes the soil to rupture both vertically and horizontally.

As a last resort, it may be necessary to remove and replace the grass and topsoil by:

- removing accumulated silt and (subject to a toxicity test) applying to land or dispose off site
- removing damaged turf, which should be composted or disposed off site
- cultivating remaining topsoil to required levels
- re-turfing (using turf of a quality and appearance to match existing) or reseeding (to Clause 12.6 of BS 7370-3:1991) using seed to match existing turf) area to required levels. It may be necessary to supply and fix erosion protection to protect seeded soil. The placing or grading of turf and seeded areas should be undertaken carefully to ensure that final design levels are achieved. Watering will be required to promote successful germination and/or establishment.

32.9 FREQUENCY OF MAINTENANCE TASKS

Landscape maintenance contract periods are usually of 1–3 years in duration. The 3-year cycle is increasingly common to ensure continuity and commitment to long-term landscape care. The frequency of regular landscape maintenance tasks in a contract period can range from daily to once in the contract period. In practice, most site tasks are based on monthly or fortnightly site visits, except where grass or weed growth requires a higher frequency of work. In many cases, a performance specification is used with terms such as "beds shall be maintained weed-free" or "grass shall be cut to a height of 50 mm with a minimum height of 35 mm and a maximum height of 100 mm" to obtain the required standards.

Frequency can be specified within the schedule to include occasional items, such as "'meadow grass' – cut twice annually in July and September to a height of 75–100 mm (or to supplier's recommendations), all arisings raked off and removed to wildlife features, compost facility or other recycling facility", which provides flexibility for work that is not critical to the management of the site.

Maintenance tasks that suit a performance approach commonly include plant growth, grass cutting, pruning and tree maintenance. However, work tasks, such as sweeping paths, regular litter collection and cleaning road surfaces, will require work at an agreed frequency, with more specific timings such as weekly, monthly or annually. Where the frequency and timing of tasks is critical, a mixture of performance and frequency specification is necessary to provide effective maintenance.

SuDS maintenance generally tends towards a frequency requirement to ensure a predictable standard of care, which can be recorded on site and provides a reasonable basis for pricing work. A convenient frequency for many tasks is at a monthly inspection, as this is the usual minimum site attendance required in a landscape specification. The monthly frequency should provide for an inspection of all SuDS components and for the checking of all inlets and outlets. The inspection should be carried out by someone familiar with the operation of the specific SuDS components, and it should be recorded.

However, certain SuDS maintenance tasks fall outside this monthly cycle and need to be accommodated in the contract. The most obvious are:

- wetland vegetation maintenance
- silt management
- filter replacement in proprietary systems
- sweeping of pervious surfaces (unless loose, gravel surfaces).

There are other tasks associated with ensuring the long-term performance of the systems that may be more difficult to predict, and may even fall outside any contract period. It may, therefore, be more appropriate to review requirements, for example, for system rehabilitation at interim periods, when contracts are falling due for renewal.

The vast majority of well-designed SuDS, whether “hard” or “soft”, do not seem to suffer from problems with excessive and rapid silt accumulation, if they apply the key concepts of the SuDS philosophy: source control with a correctly designed Management Train. The frequency of sediment removal will increase as the area of the catchment increases in relation to the surface area of the SuDS where sediment accumulates (whether this is within a proprietary system or a landscape feature).

32.10 APPLYING THE PRINCIPLES OF LANDSCAPE MANAGEMENT

Typical landscape management documentation and its potential application to SuDS is summarised in the following subsections.

32.10.1 Management plan

This document should include a clear statement of design intent and an explanation of each of the SuDS components and the benefits being delivered by the SuDS for the site. The document should describe the management objectives for the site over time, and the management strategies that should be employed to realise these objectives and reconcile any potential conflicts that may arise.

Where the drainage system has an impact on the wildlife value or public use of a site, the document should explain any habitat enhancement goals, health and safety issues and long-term management implications.

For SuDS, the management plan should include a Maintenance Plan, which will be required so that maintenance aspirations can be costed, in order to secure their long-term financing. The Maintenance Plan can also establish changes in maintenance regimes that may be required to match changes in objectives such as the need to adapt operation and maintenance practices to accommodate specific wildlife habitats that may develop.

Sites with special wildlife or amenity interest may require detailed management plans that monitor habitat development, infrastructure changes or damage to sites, and ensure rapid responses to such changes, should they occur. In these cases the management plan should be prepared in collaboration with an ecologist. Ecological supervision may be required for certain works.

It is common for smaller commercial, industrial and housing sites to have a simple maintenance statement. In this case, a single page explaining the site management (including the SuDS) would be useful for all parties involved in the care of the development.

An important part of a management plan is an annual and 3–5 yearly review of the Maintenance Plan (when maintenance contracts are typically renewed). This should apply to all types of SuDS, but is particularly important for the soft landscape element, as plants and trees require different periodic management techniques as they develop. The review should involve those responsible for the maintenance and those undertaking the work.

The management plan should be a living document that is reviewed periodically with reference to changes on site, as well as changes to adjacent sites that might impact the site.

Further guidance and an example of a Maintenance Plan (in the form of a checklist) is provided in **Appendix B**.

32.10.2 Conditions of Contract

Appropriate conditions of contract will be required. Advice can be sought from the Landscape Institute which publishes specific landscape maintenance contracts. Guidance is also provided in Shaffer *et al* (2004).

32.10.3 Specification

The specification details the materials to be used and the standard of work required.

A specification, usually preceded by preliminaries, details how work shall be carried out, and contains clauses that give general instructions to the contractor. It will normally be accompanied by a schedule of work (**Section 32.10.4**). Specific SuDS maintenance clauses may be included in a general specification or as a separate "SuDS maintenance specification" section either within or referenced by the management plan (**Section 32.10.1**).

32.10.4 Schedule of work

The schedule of work itemises the tasks to be undertaken and the frequency at which they will be performed.

The tasks required to maintain the site and the frequency necessary to achieve an acceptable standard should be set out in the schedule of work.

This document (and **Section 32.10.3**) will often form the basis of a pricing framework, and can also act as a checklist to ensure that the work has been carried out satisfactorily.

For further information on the development of appropriate schedules, see HR Wallingford (2004).

32.10.5 Maintenance record

It is vital that a record is kept of the inspections and maintenance work that has been carried out. This allows the response of the system to different maintenance regimes to be assessed in future, and also provides protection against legal claims should the capacity of the system be exceeded during a rainfall event and flooding occurs elsewhere as a result.

32.11 REFERENCES

HR WALLINGFORD (2004) *The operation and maintenance of sustainable drainage systems (and associated costs)*, SR 626, HR Wallingford, UK. Go to: **http://tinyurl.com/lcot2g6**

ROAD LIASON GROUP (2005) *Well-maintained highways. Code of practice for highway maintenance management*, The Stationery Office, London, UK (ISBN: 0-11552-643-9). Go to: **http://tinyurl.com/osm2juc**

SHAFFER, P, ELLIOTT, C, REED, J, HOLMES, J and WARD, M (2004) *Model agreements for sustainable water management systems. Model agreements for SuDS*, C625, CIRIA, London, UK (ISBN: 978-0-86017-625-1). Go to: **www.ciria.org**

STATUTES

British Standards

BS 7370-3:1991 *Grounds maintenance. Recommendations for maintenance of amenity and functional turf (other than sports turf)*

Regulations

Construction (design and Management) Regulations (CDM) 2015

33 WASTE MANAGEMENT

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Chapter 33

Waste management

This chapter discusses the principles of good practice for the management of waste resulting from maintenance of SuDS.

33.1 INTRODUCTION

SuDS remove pollutants from runoff, thereby minimising the impacts on receiving water quality. A key part of this process is sediment management. Sediment accumulates in SuDS for two main reasons:

- surface water runoff brings debris and silt loadings from hard surfaces
- green areas and vegetated systems generate organic waste, due to plant growth and die-off.

If sediment is not removed from the drainage system at appropriate frequencies, there is a risk that the following problems could develop:

1. SuDS components can become sources of pollutants as the inorganic and organic sediments that accumulate on their base become resuspended during storm events.
2. Storage capacity may be reduced.
3. The risk of inlets and outlets blocking may increase.
4. Amenity and aesthetic value could decrease because of odours and vectors (organisms that carry disease-causing microorganisms from one host to another).

To prevent these problems, SuDS (and their pre-treatment structures, if present) should be periodically inspected, the level of sediment (and other waste) accumulation should be monitored and the systems cleaned when appropriate. Sediment and vegetation that is grown in components where contaminant loadings are high may contain a variety of pollutants, and proper handling and disposal of these materials is essential.

Materials such as sediment, vegetation, contaminated geotextiles and other structural material arising from the maintenance of SuDS may be classified as “controlled wastes” and where this is the case, their removal and disposal must always be in accordance with the latest regulations and legislation. This chapter refers to legislation that is current at the time of writing (2015), but may be amended over time. It is, therefore, the responsibility of the SuDS operator to keep abreast of the latest information and requirements. The environmental regulator should be contacted to confirm the required protocols for the proper handling of any sediment or other waste at a particular site.

33.2 WASTE MANAGEMENT REQUIREMENTS

33.2.1 General

There are usually three types of waste arising from regular SuDS maintenance: litter, green waste (vegetation) and sediment. Litter should be disposed of as for any open space. Green waste management is described in **Section 33.2.2** and sediment management is described in **Section 33.2.3**.

Directive 2008/98/EC (the Waste Framework Directive) requires all member states to take the necessary measures to ensure that waste is recovered or disposed of without endangering human health or causing harm to the environment. This includes requirements for permitting, registration and inspection of waste disposal facilities and operations.

UK waste legislation is derived predominantly from European Union (EU) laws and transposed into UK law via various statutory instruments specific to England and Wales, Scotland or Northern Ireland. The current regulatory constraints and obligations for waste management and disposal should be established through consultation with the environmental regulator.

The guidance on complying with the latest regulations is summarised on the following websites:

- England and Wales: **https://www.gov.uk/waste-legislation-and-regulations**
- Scotland: **www.sepa.org.uk/waste.aspx**
- Northern Ireland: **www.doeni.gov.uk/waste**

Where waste is removed from site, it will be subject to the relevant waste management legislation for the country. In brief, this generally means that those responsible for generating waste must:

1. adequately characterise and describe the waste to allow for its safe disposal
2. only allow the waste to be removed and transported by those who are licensed to do so
3. ensure that it is disposed at a suitably licensed waste disposal or treatment facility.

The producer of the waste will be required to undertake analysis of the waste, including the CEN leaching test, so as to properly characterise the waste as hazardous, non-hazardous or inert, to assign a classification in accordance with the European List of Wastes (EC, 2000) and to provide a full description for the receiving landfill. There is a further requirement to pre-treat hazardous waste for volume reduction, to make it non-reactive and to improve its physical stability. A landfill can only accept waste provided that the appropriate waste acceptance criteria are met. More information is available from the WRAP website: **www.wrap.org.uk**

If wastes arising from the maintenance of SuDS are to be disposed of through beneficial reuse, the proposed activity will need to meet the requirements of an appropriate exemption and, having done so, be registered. The exemption registration process requires a burden of proof in demonstrating that the conditions of the particular exemption are met and that the activity is unlikely to cause pollution of the environment or harm to human health.

Waste disposal options that may be possible include the following:

- Non-contaminated sediments or sediments with low levels of contamination arising from SuDS could possibly be placed on the land surrounding the SuDS (without planning permission), provided that (1) the disposal area is within the operational land of the SuDS owner (2) the land is not used for agriculture and (3) it can be demonstrated that the deposit results in an ecological improvement to the land. See EA position statement requirements (**Section 33.3**).
- Green waste may be composted on site under an appropriate exemption. Alternatively, green wastes may be collected by a commercial operator for processing into compost at their own site.
- If SuDS could be excavated in the dry, then recovered sediments could be beneficially reused as "building material", for example to raise banks or for other landscaping. However, if wet excavation occurs, the material can only be used in land drainage works.
- Direct dredging of the sediments to the surrounding banks may be possible if there is demonstrable benefit to agriculture or ecology.

The waste disposal route and proposals should always be confirmed with the environmental regulator before sediment or green waste is removed from the site or applied onto land within it.

In some landscape features with specific habitats, sediment removal operations may require adequate method statements that are prepared in liaison with an ecologist. The method statement should take account of the time of year, sequence of operations on site and disposal of waste. In some places, waste material may need to be retained on site for a period of time to manage movement and relocation of invertebrates. Adequate time and resources may also have to be allocated, to transplant vegetation in sensitive zones.

33.2.2 Green waste management

The relevant waste management regulations must be followed when removing and disposing of green waste. Where green waste is cut from areas subject to low levels of contaminants, it may be possible to compost and reuse it.

Larger corporate sites or public open spaces and communal residential land with dedicated management facilities may incorporate composting facilities of a suitable scale using contained structures/bins (with ventilation) or open bays. For efficient compost management, at least two or three bins/bays are required, and the compost needs to be mixed/turned by suitable machinery (eg JCB bucket) at a regular frequency (see below).

A compost facility allows all green waste, particularly grass cuttings and prunings, to be recycled and to provide compost for mulching ornamental plant beds. The following process should be followed for composting:

- shred all arisings from site
- combine all arisings in active compost bin with grass cuttings not exceeding 70%
- turn and mix active compost when bin is > 50% full, at weekly intervals for at least 4 weeks
- turn and mix full bin every 28 days until used
- combine adjacent compost bins/bays when contents are settled to 50% volume reduction
- use compost after 3–4 months.

Where there is no facility for composting on site, green waste can be removed to an off-site dedicated composting facility where the material is used to make compost to PAS 100:2011 or to the Compost Quality Protocol by EA (2012). Any third-party sites need to be appropriately permitted.

Some prunings (supplemented with occasional grass and other non-woody cuttings during the summer) can be used to create or enhance hibernaculae or other facilities on the development site, where this is part of the landscape or biodiversity strategy. Such facilities can provide refuges, hibernation shelter, food and egg laying sites for a large number of animals (commonly known as wildlife piles) (RSPB, 2015).

33.2.3 Sediment management

Silt/sediment collected from a SuDS component will often contain low levels of metals, hydrocarbons and other pollutants.

Any sediment removed from SuDS must meet the requirements of relevant waste management legislation.

The Environment Agency has adopted a risk-based approach in relation to removal of sediment from SuDS in England and Wales (EA, 2011), but at the time of writing there is no comparable SuDS-specific approach in Scotland or Northern Ireland.

The approach within the position statement can be summarised as follows:

1 Evaluate whether the silt/sediment collected in the system is likely to have a high risk of being defined as "hazardous waste". This will mainly be based on the land use within the catchment (eg industrial or heavy vehicle management areas or end-of-pipe ponds without source control; basins etc without source control).

2 If this is the case, then proceed to "hazardous waste" disposal. This will require chemical analysis of the silt and compliance with all relevant legislation and guidance.

3 Where there is low risk of pollution (eg housing, schools, commercial sites with source control) then a "sustainable" approach to waste management should be agreed with the environmental regulator. This may require confirmation of the levels of contaminants but, provided that they are below acceptable limits, should allow removal and land application to suitable vegetated surfaces outside the SuDS design profile but still close by (eg within 20 m of the SuDS component). For any adverse silt accumulation in wetlands and ponds (this should be very low if effective source control/pre-treatment is in place), the material should be removed, allowed to de-water by the side of the SuDS component for 24–48 hours and then land applied in a similar manner. These activities will need consideration of the potential impacts to amenity (particularly aesthetic) and biodiversity performance, and specific constraints (eg relating to protected species and specific habitats, **Chapter 32**).

If land application is not appropriate for low-risk sites, the sediment will have to be disposed off site. If material is removed off site, the site owner and those carrying out the work must comply with the required legislation (**Section 33.2.1**).

The waste disposal route and proposals should be confirmed with the environmental regulator before silt is removed from site.

33.3 SEDIMENT CHARACTERISATION AND DISPOSAL

Sediments in surface water runoff have properties that are site specific, and it is extremely difficult to give "typical" sediment characteristics. The surface layer (approximately the top 5 cm) is likely to be high in organic matter, have a high water content, and a low density.

Testing for the presence, concentration and toxicity of metals in both the UK and the USA has indicated that extracted sediments tend to be non-hazardous to human health as defined by current standards (environmental quality standards). Nutrient concentrations in pond sediments are generally significantly lower than nutrient concentrations found in combined sewer overflows. Currently, there are few datasets available on the presence of total petrohydrocarbon (TPH) and polyaromatic hydrocarbon (PAH) concentrations in sediments. Urban surface water sediments may also contain bacteria and viruses, including faecal streptococcus and faecal coliform from animal and human wastes – particularly where there are foul sewer misconnections in the catchment.

Surface water runoff may also contain traces of fertilisers, herbicides and household substances such as paints and cleaning materials, which may contain substances that are potentially hazardous.

Sediment disposal options will depend largely on the concentrations of the pollutants in the sediment. The decision-making process is summarised in **Figure 33.1**. This flowchart applies to sites where the EA position statement (the deposit and de-watering of non-hazardous sites from SuDS on land) does not apply. The EA (2011) position statement allows the land application of sediment from SuDS in low-risk sites (to an area outside the design profile of the SuDS).

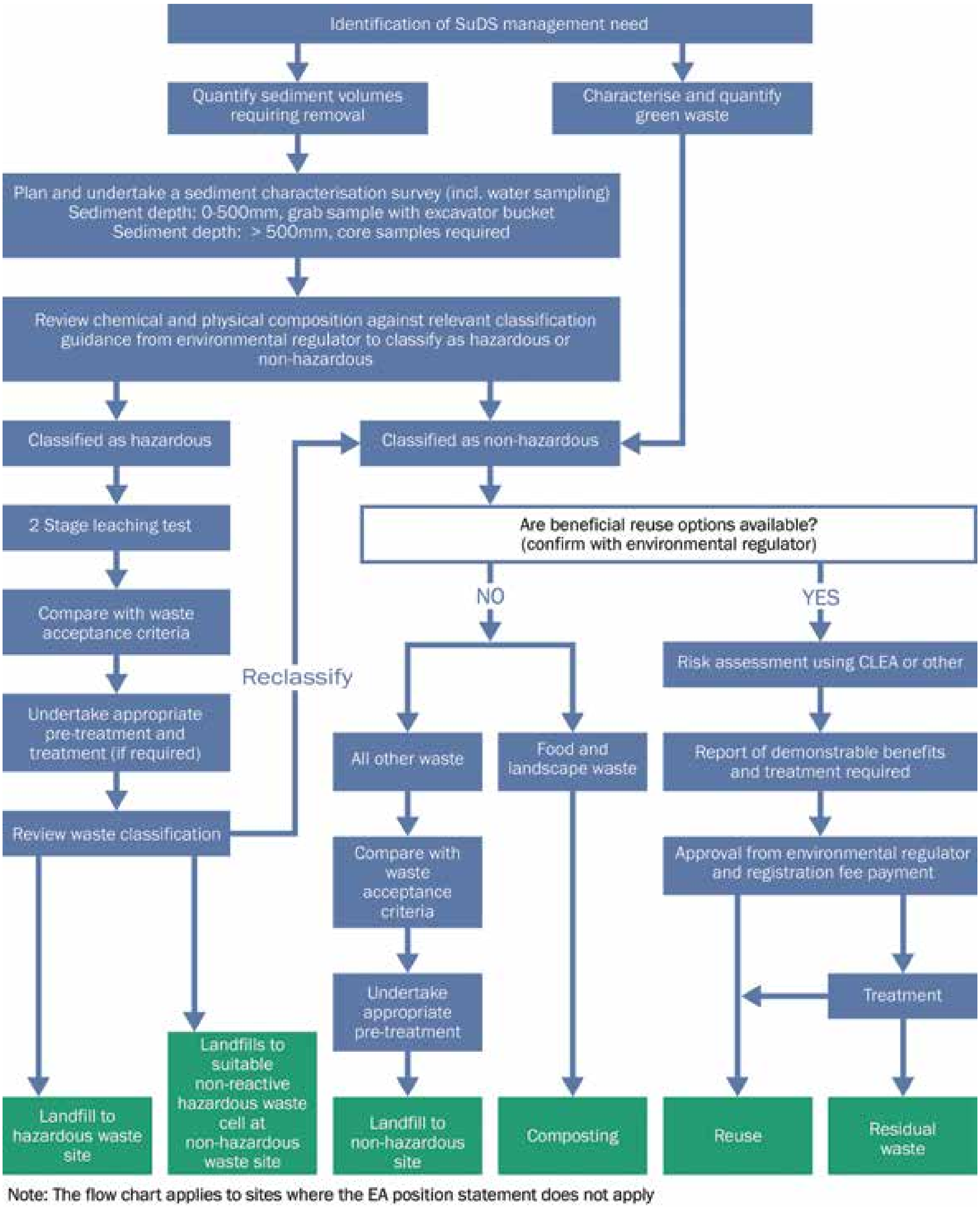

Figure 33.1 Sediment categorisation and associated disposal options (from Kellagher *et al*, 2006)

33.4 REFERENCES

EA (2011) *Regulatory Position Statement. The deposit and de-watering of non-hazardous silts from sustainable drainage systems (SUDS) on land*, MWRP RPS 055, Version 2.0, Environment Agency, Bristol, UK. Go to: **http://tinyurl.com/p4478yo**

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KELLAGHER, R, WOODS BALLARD, B and BARNFORD, S (2006) *SUDS – Increased liability for the water industry – Phase 2*, UK Water Industry Research (UKWIR), London, UK (ISBN: 1-84057-417-8). Go to: **http://tinyurl.com/pxrtu9h**

RSPB (2015) *Building a hibernacoulum*, web page, Royal Society for the Protection of Birds, Bedfordshire, UK. Go to: **http://tinyurl.com/qfljcx9**

STATUTES

Directives

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance) (Waste Framework Directive)

Standards

BSI PAS 100:2011 *Compost specification*

Image courtesy University of Northampton

34 COMMUNITY ENGAGEMENT

Contents

Chapter
34

Community engagement

This chapter provides an overview of good practice, including two case studies for SuDS schemes.

▶ *Many other documents are available that provide more detailed guidance on community engagement in general or for other water related projects, including Daly et al (2015a and 2015b), EA (nd) and Cornell (2006).*

34.1 INTRODUCTION – WHAT IS COMMUNITY ENGAGEMENT?

Community engagement is a planned process of working with specific groups of people (connected by location, particular interests or membership of an organisation) to address issues affecting their local environment and to unlock opportunities to improve it. It can take many forms and cover a broad range of activities, which (in the SuDS context) will help to ensure that the community understands and engages with proposals that are intended to benefit them, such as reducing flood risk (**Section 34.2**).

Effective community engagement requires a broad section of the community to participate. This can be encouraged if the process is open, welcoming to all members of the community, has clear goals and is well organised.

SuDS can be integrated within new developments to deliver drainage as part of attractive sustainable environments or retrofitted into existing development to address flooding or sewerage capacity problems experienced within the community. These two types of project have different needs and outcomes from community engagement:

- **For new build**, pre-project engagement will focus on the impact and integration of the proposed development (including the SuDS) and the new community on those already living in or visiting the area. It is essential that new owners are informed that their property is drained by SuDS, and how the drainage works. However, once new residents move in, there may then be considerable benefit for the developer/SuDS owner in engaging with them, so that they understand how their system functions, its importance, its maintenance requirements and any charges or responsibilities that may fall to them. This could also be an opportunity to address any specific concerns they may have, for example relating to health and safety (**Chapter 36**).
- **For retrofit schemes**, pre-project engagement will tend to be more focused on the objectives of the scheme, the needs of the existing community and potential design options. This is necessary to ensure that the final scheme maximises benefits for the community, to secure support and acceptance by the community before implementation, and to encourage participation in any maintenance requirements following construction.

While SuDS is the focus of this document, it is likely that in some situations SuDS may only be a minor part of a larger development, surface water or flood risk management project that requires community engagement.

Community engagement can take many forms and can cover a broad range of activities. In general terms, engagement can take one or more of the following forms, and sometimes can progress from one to the next as the project develops:

- **Informing** the community about a planned project (eg a new development nearby or a planned retrofit surface water management scheme) is not true engagement, although it is sometimes necessary, and can be used in the preparatory stages of an engagement process.

- **Consulting** the community can be part of a process to develop plans/design options for a project or activity, or to build community awareness and understanding around a particular issue (eg regarding health and safety concerns over new bodies of open water close to their homes).
- **Involving** the community in a project (eg a SuDS planting day, setting up a SuDS maintenance group, or initiating an environmental group linked to the SuDS flora and fauna) or activity can help to ensure that their issues and concerns are understood and considered as part of the decision-making process (eg a local SuDS discussion group that includes the designers and promoters of the scheme).
- **Collaborating** with the community to develop partnerships can then be used to develop options and provide recommendations around the project or initiative (eg inputs to setting the required maintenance regime, mechanisms for raising concerns over the performance of the system, or designs for a range of potential retrofit options).
- **Empowering** the community can enable them to make informed decisions and to implement and manage change (eg educating the community about sustainability issues and how managing surface water in the right way can protect the environment and deliver benefits to them).

The form of engagement undertaken will depend on what the engaging organisation wishes to achieve, either as an end result or at a particular stage in the engagement process (**Section 34.4.1**).

Understanding what level of participation is needed is also important and will determine the most appropriate way to go about it (**Section 34.3**).

34.2 THE BENEFITS OF SUCCESSFUL ENGAGEMENT

Where community engagement is most successful, both the community and the engaging organisation will benefit.

34.2.1 Community benefits

A well-planned community engagement process should ensure that a wide diversity of opinions are heard and considered in the process, so that the community as a whole feels that its input is valued.

Benefits for the community may include the following:

- Communities can be assisted to identify priorities for themselves, such as which parts of an estate need to be retrofitted first, if a project is undertaken in phases.
- The engagement process provides a mechanism for increasing a community's knowledge of environmental and sustainability issues, and is an opportunity to learn for themselves and their families. Communities can use the process as a trigger to facilitate the setting up of environmental/ SuDS working groups to help inspect, maintain or promote educational initiatives relating to the biodiversity associated with the scheme.
- Engagement can help develop a "local voice", and establish a longer-term input to local decision making.
- Where a community shares in the decision-making process, they are much more likely to take ownership of the outcome, whether it is related to a current flooding problem or plans to make their community more resilient for the future.
- Participating in the engagement process can foster a greater sense of belonging and overall community cohesion, with benefits beyond the remit of a specific engagement.
- Ultimately, individuals may become empowered through the process, and become a proactive part of the group determining the issues affecting their community or by leading community initiatives.

34.2.2 Benefits for the engaging organisation

The benefits for the engaging organisation (plus client and funders) from an effective community engagement exercise can be substantial, not only benefiting the specific project but the organisation more generally too. Community engagement can often be seen as a risky and difficult aspect of a project, but if undertaken well and when started early in the design process, it can add real value, and enable the project to proceed more smoothly.

Benefits for the engaging organisation may include the following:

- Community input can ensure that the proposals are framed to suit the community's preferences, as well as delivering the overall objectives of the scheme.
- Potential issues of community concern, particularly around subjects such as safety or parking, are likely to be identified earlier in the process, thereby increasing the likelihood of a viable and acceptable scheme.
- Community understanding of the purpose and function of the drainage system is important in educating the public to embrace the inclusion of SuDS and to encourage them to take ownership and potentially to be involved in its longer-term maintenance
- Engaging with communities can enable the organisation to explore ways in which they can work more closely on issues of concern to the community. These concerns can often be different from those the organisation may have anticipated.
- Early engagement in the planning process can help to ensure that an organisation deals with local concerns in a proactive way, instead of needing to react to partial or poor information in later project stages, which could generate distrust, tensions or delays and extra cost.
- Addressing local concerns may allow broader multiple benefits to be explored and incorporated within the scheme, resulting in better value for money.
- Good engagement can enhance the reputation of the engaging organisation as being a body open and willing to listen, and can help to ensure that any future engagements and projects are potentially approached with a positive attitude by the community. It also means that the organisation is more likely to secure positive publicity from the project.

34.3 DEVELOPING AN ENGAGEMENT PLAN

Community engagement should not be undertaken without a well thought out engagement plan and the right team to implement it from the engaging organisation.

Each engagement plan will be different and will be dependent on the size and complexity of the project (**Section 34.3.1**) who will be engaged (**Section 34.3.2**) and the resources available to the engaging organisation (**Section 34.3.4**).

34.3.1 Defining what needs to be done

The reasons for engaging with the local community will vary from one project or site to another. There should be clarity and agreement within the project team from the beginning regarding what the community engagement exercise is expected to deliver and what would be deemed a success (**Section 34.3.3**).

If the purpose of the engagement process is clear to the project team, there is a better chance that it can also be made clear to the community; so it is important that there is clarity regarding roles within the engagement process within both the project team and the community (**Sections 34.3.2 and 34.3.4**).

The engagement process should focus on delivering an overall aim (eg we want to reduce flood risk for the local community) rather than specific outcomes (eg we want to build 20 rain gardens). Care should be taken to ensure that the community does not feel that specific outcomes have been predetermined. Therefore, where the engagement seeks to enable the community to influence design decisions, it should be clear about which aspects of the design are flexible and which are fixed. There is little point in engaging if there is no flexibility in the outcome and the design team needs to open to allowing engagement to shape the outcome.

The type and scale of engagement needed will vary depending on the size of project (ie how large a community will it affect) and complexity (eg how unusual is the scheme being proposed or how complex are the problems being addressed). A small infill development will not need significant community engagement. A large urban regeneration project that will be looking to maximise the opportunities to retrofit SuDS may require a relatively large community engagement exercise with multiple stages and involving as much of the community as possible. Where a wide range of organisations or groups are invited to participate, they should each be encouraged to present a single view wherever possible, rather than presenting the views of individuals.

The engagement needed will also vary during different stages of the SuDS design process (**Chapter 7**). Where the engagement is taking place during the early stages of the design process, it is usually beneficial to have a wide range of participants to ensure that a wide range of opinions are considered. Where engagement is taking place during the later stages of the design process, it may be more appropriate to have more focused groups of participants to look at specific issues.

Flexibility is an important requirement to factor into the engagement plan. The outcome of engaging with the public can never be fully predicted. Further stages may be required if unexpected issues arise. Alternative forms of engagement may be required if one form of engagement is not as successful as anticipated (**Section 34.4.3**).

For large projects, it can be useful to plan the engagement process with the assistance of the community (ie the first engagement stage is to plan the other stages).

Once the purpose of the engagement has been agreed and the type(s) of engagement have been considered (**Section 34.1**), then the plan for delivery should reflect that focus throughout, including:

- being clear about the role of the community
- involving the community in appropriate ways that are meaningful
- clarifying the extent to which people can influence decisions
- explaining the stages, and at which stage different decisions will be made
- managing expectations over the outcome by being realistic about what can be achieved.

Being realistic is particularly important, otherwise the process can lose credibility if the expected outcomes are not met.

The scope of the engagement exercise should be defined in terms of the engagement stages, how they are delivered, the resources available to deliver them, and the timescale within which an outcome needs to be delivered. **Section 34.4** provides guidance on delivering engagement.

34.3.2 Identifying who needs to be involved

To get the most value from community engagement, the first step is to understand who is part of the community. This process of stakeholder analysis can potentially cover a wide range of individuals and organisations coming from a range of sectors, such as:

- public and private sector organisations, local trusts or voluntary bodies and environmental, conservation or community organisations
- utility companies and service providers in the area, such as the water company, highways authority and local trash/recycling companies
- all potentially affected landowners

- those who have a role in local decision making or regulation, such as the planning authority, the environmental regulator or the internal drainage board
- those who live or work within a specific geographic area, such as those who may live within an area with a known flood risk, including both those who are likely to be affected and those who think they may be
- those who may have the ability to affect the project in their own right, or who are known to be in favour of, or against the project (such as members of parliament, local councillors and community leaders).

Consideration in defining who to engage with can usefully be undertaken through the community itself, as in many instances it can be better placed to help identify the broadest range of stakeholders. Care should also be taken to ensure that those engaged include the widest range of people in terms of diversity, including age, gender, ethnicity, vulnerability and disability. Some sections of the community may be less vocal than others and a suitable means for them to provide their views should be considered.

If an engagement event needs to be focused on a specific issue, it may be appropriate to target specific organisations and individuals to participate. This can be important at critical stages of the engagement process to ensure its effectiveness. Should this be necessary, there may be a need to follow this up with more inclusive events to retain collective ownership within the community.

A database that can be cross-referenced for people and organisations or other associations should be set up early in the process. Any database must be set up having fully understood the requirements of the Data Protection Act 1998. This database should have details of who has been contacted, who then engaged in the process, when and how. This provides a very useful tool for ensuring that people remain engaged (as appropriate) and can be used for evaluating effectiveness (**Section 34.4.3**).

Individuals or groups should be given the opportunity to decide how they want to be involved – whether directly or through their group, and whether they wish to be active or to just receive information about the project.

Other issues that should inform how the engagement is handled with the stakeholders/community could include:

- discovering how previous engagements with this community may have been handled, and their degree of success, while not assuming that this project will be the same
- understanding what else is happening within both the community and local community groups to ensure that there is no confusion between the project and any other activities locally, and whether there are any potential synergies with such activities (eg are there any opportunities to share a platform?)
- working with existing local partnerships to access particular sectors of the community; they may also be able to assist with developing the engagement plan
- ensuring that those most vocal are involved, but not allowed to dominate
- ensuring that any engaged group is properly representative
- deciding how to include people at various stages if they become interested later in the process
- considering how to work with other decision-makers or regulators and at what stage in the process; an early discussion around this is likely to be helpful.

34.3.3 Encouraging participation

The level of participation (ie the degree to which committees, groups or individuals are actively involved in formulating a specific project or outcome) needs to be carefully considered.

Generally, where the level of participation is high, with people learning and making decisions together, the level of ownership of those decisions is also likely to be higher and, consequently, the project is likely to be more successful. Also, the greater the involvement of the public within the engagement, the greater their impact can be on the outcome.

However, a high level of participation brings with it responsibilities. It is important to avoid promising or implying a level of participation or decision making that is not intended or not achievable. Processes that claim to be empowering but merely offer "token" levels of participation should be avoided, as this can undermine the engagement process.

34.3.4 Having the right engaging team

Good leadership that is consistent throughout the project is essential, to ensure that a consistent clear message is given and that the public know who to contact.

Project/engagement team members may come from within an organisation, or they may be external, depending on the skills required. There are organisations that can be brought in to a project team to undertake detailed engagement with communities.

The composition of the project team may also change throughout the development and implementation of the engagement plan and should reflect the skills required at each stage. The early stages may need those with good external relationship skills, whereas the later stages may require those with more technical expertise (see **Case study 34.2**). Where communities are encouraged to take an active role, some individuals within the community may need training or assistance to enable them to contribute fully, as it is important to have individuals who are good listeners and communicators.

Those involved in the project will need a range of experience and skills, which could include: local knowledge, familiarity with community engagement processes or existing relationships with the community or other stakeholders. Consideration should also be given to the level of diversity within the team and how that may reflect the community (and whether it needs to).

34.3.5 Managing risks

There is always a risk when undertaking community engagement that it may not achieve an acceptable outcome for the organisation, or that the community does not engage in a way that allows the process to be effective. Identifying the key individuals in the community or finding a local "champion" can help to reduce this risk; this is usually effective and is good practice.

Should any conflicts or problems arise as part of the engagement process, this should be addressed openly and in a timely way to reduce the risk of it damaging either community relations or the outcome of the process. As part of this process, a time frame or deadline should be agreed to respond to any concerns raised.

Risks are best managed by having a monitoring/evaluation process in place during the engagement process (**Section 34.4.3**).

34.4 DELIVERING ENGAGEMENT

A wide range of methods or tools are available to support the engagement process. Those selected will be dependent on the desired outcome at each stage in the process. Early in the engagement process methods and tools selected may be more general, whereas at a later stage discussion and information will be needed in much greater detail and much more focused, to support the evolution of the process.

34.4.1 Communicating effectively

Communicating effectively with the community is a key part of the engagement process. Communication can be one way (providing information) or two way (involving discussion, problem-solving etc).

When providing information to a community about a project, it is essential to know who the information is for, how they are most likely to access it and what is the best way to ensure understanding.

At every stage all information should be:

- high quality
- consistent in the message it is communicating
- appropriate to the specific stage of engagement
- timely, ie provided at the right time in the project
- targeted towards the people who will receive it
- clear, interesting and easily understood by those receiving it
- explicit about whether a response is required and, if so, how to do so
- clear about the contact details for further information.

As individuals access information differently, it may be necessary to provide it in several different formats, such as on a website, through an exhibition or by a paper distribution. Information should also acknowledge local cultural and social needs including language, times of availability and local religious or cultural events such as festivals, which could prevent participation. Practical approaches that demonstrate how a scheme may work or look (using models, marking it out on the ground or using a mock-up) can be highly effective, particularly for the many people who are not familiar with interpreting two-dimensional plans and elevations. The use of clear and concise case studies of similar projects can also be very useful to show that successful outcomes can be achieved and what they look like.

Transparency in all communications is vital. Issues that are currently adversely affecting members of the community, such as flooding, or could adversely affect the community as a result of the project, such as access or parking for vehicles, and health and safety concerns regarding open water, should be treated with sensitivity. This will then encourage trust and a co-operative working relationship. Access to statistical information regarding specific concerns, such as parking, is particularly helpful to enable discussions to be based on facts rather than speculation or perception. This information can then also be used to help measure the subsequent success of the project.

The techniques for communications are extremely varied, and will include both meetings and other events, as well as the provision of information (either by the engaging organisation or by the community). Examples include:

Meetings and other events

- open house sessions
- public meetings
- workshops/design charrette[1]
- site visits
- smaller focus groups
- one-to-one sessions
- surveys/questionnaires
- interviews.

Note:

1 A type of workshop used as part of the planning process to engage stakeholders, usually public engagement events.

Provision of information

- web site – may be a dedicated site for the project, or part of an existing organisation's website
- local TV or radio – local interest features, announcement of local events

- blogs or social media – useful to keep people updated throughout the process
- videos
- newspaper articles
- interpretation boards – at different stages of the project, to inform people, and in the long term for educational purposes around the SuDS purpose, and its need for long-term management and maintenance
- manned displays/exhibitions
- models – both to demonstrate what a scheme will look like, but also as part of interactive design sessions
- fact sheets/leaflets
- letters
- door knocking.

Guidance on a wide range of techniques for communication and engagement is provided in Daly *et al* (2015b).

Ensuring that information about the project and events reaches the target audience is fundamental to its success, so using local channels of communication, particularly through community groups, can be very effective. Consideration should also be given to the need to provide information/translation into different languages. The timing and location of events or meetings should be arranged to make them accessible by the widest range of people, and should ideally be local to the project and include options for meeting/attending outside working hours or at weekends.

The quality and abilities of individual facilitators at public meetings is also crucial in delivering effective outcomes. They should understand and be able to use a range of techniques which encourage attendees to overcome barriers, whether real or perceived, so they can participate effectively.

Where responses are requested through a questionnaire or interview, such information should be dealt with appropriately and sensitively, also bearing in mind the provisions of the Data Protection Act 1998. Questionnaires should be carefully constructed to ensure that the questions are clear, simple and unambiguous, do not lead the respondent to specific answers, are relatively short in length and state clearly that the replies will be kept anonymous.

34.4.2 Maintaining engagement and education

Once the engagement process has been started, regular reporting both within the engaging organisation and to the community will be important to maintain trust and to keep channels of communication open and effective. All engagement activities should have a follow-up step, where the outcomes are shared and progress is reported.

Where groups have been set up for collaborative engagement, these will require management to maintain their interest, commitment and enthusiasm.

Where groups have been empowered to act independently within agreed guidelines, these will also need ongoing liaison to ensure that they adhere to their stated intention and purpose, and that they are prepared to continue with the projects they have taken on.

Community engagement for all SuDS projects should include making the public aware of the wider objectives of sustainable water management and the reasons why the SuDS scheme is important and needs to be maintained throughout its lifetime (in some cases with their involvement). Methods of providing a long-term educational resource or reminders should be considered. Working with schools or community groups can be effective in this respect, as children are a useful conduit for educating their parents and securing their involvement.

34.4.3 Reviewing and evaluating effectiveness

Evaluating the effectiveness of a community engagement process is important, as lessons can then be used to inform future engagement processes and help to manage risks (**Section 34.3.5**). The engagement process should be monitored and evaluated during the process, not just afterwards, so that the process can be adapted as necessary.

Useful questions to consider include the following:

- Were the original objectives achieved or not, and why?
- How effective were the methods used?
- What information/events did you use?
- What proportion of the community did you reach?
- Did it represent all aspects effectively?
- What would you do differently another time?
- What did the participants think of the engagement process?
- Was it worthwhile for them?
- How much time and money did the process take – more/less than anticipated?
- Is the communication process still continuing?
- Did the process deliver a recognisable benefit?

CASE STUDY 34.1 **Upton – large-scale housing estate**

Figure 34.1 Installing SuDS on the model (courtesy University of Northampton)

Figure 34.2 Replacing impermeable surfaces with porous surfaces (courtesy University of Northampton)

Detailed engagement and education around long-term use and management

Upton Meadows, to the north-west of Northampton, is a sustainable urban extension, and will provide 1200 new homes on 10 ha of land, once completed. SuDS were incorporated in the master plan and design code in 2001, with stakeholder and community engagement playing a key part in decision making. The design team from the Prince's Foundation for Building Community led an Enquiry by Design (EbD) process and facilitated a dialogue with all local key stakeholders, government organisations and agencies, enabling the outcomes of the EbD to influence the final design code for its development. The need to mitigate any additional flood risk arising from the development of Upton Meadows was a major issue locally, particularly after the severe flooding downstream in Northampton during Easter 1998.

The new community at Upton has gradually established since building commenced in 2003, and the SuDS, designed with ecological processes in mind, have developed naturally with significant

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CASE STUDY 34.1 **Upton – large-scale housing estate**

biodiversity gains over time. Since 2003, environmental and social impacts of the site have been studied, and in 2012 the Prince's Foundation for Building Community, working with the University of Northampton, set up a research project to understand how to engage the community with the natural capital (the SuDS and green spaces) within Upton. The project explored:

- the level of appreciation of residents of the urban design features within the development, including the SuDS
- whether the residents valued the green spaces and used them
- whether residents connected the green spaces and natural capital at Upton to their own health and wellbeing
- the level of awareness among residents of how the SuDS at Upton work, and how these systems contribute to the natural capital within their residential development.

Stage 1 – Questionnaire

A questionnaire was delivered to over 170 homes over a 2-month period, with 58 households returning them (34% completion rate). The questionnaire was split into five sections, one of which dealt specifically with attitudes around SuDS. Responses related to green space generally, which includes SuDS were:

- 77% of the residents thought the green spaces around the development were important
- 91.4% of the residents said they actually go out and enjoy the surrounding green space at Upton Meadows
- 81% of residents believed that the green space makes Upton a healthier place to live
- 74% thought that their quality of life had improved.

Specific responses related to the SuDS were:

- over 58% of residents stated that they believed they knew how their drainage systems work, yet only 34% said that they were given any formal information on SuDS before moving into their properties
- 3% felt that the swales and ponds could be a health risk
- 69% of residents enjoyed seeing dragonflies there
- 83% also liked the idea that frogs and newts were found in the swales and ponds
- only 7% of respondents feared that blockages would cause flooding.

There was a highly positive correlation that indicated that the same residents who thought the water made the development more attractive also did not mind the swales, and 29% of residents perceived that their property value has increased due to the design of the swales and ponds surrounding Upton Meadows.

These responses informed how the following activities were developed.

Stage 2 – STEM activity day and community SuDS fair

Based on the positive responses to the questionnaire, the natural capital project team organised two events to stimulate community learning and engagement:

- a science, technology, engineering and maths (STEM) activity data at Upton Meadows School
- a community SuDS fair.

STEM activity day

A range of stakeholders were involved in this day, which was held at Upton Meadows Primary School for their staff and pupils. The following organisations and people were involved:

- the Prince's Foundation organised sponsorship and the loan of a large SuDS model from Heriot Watt University

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CASE STUDY 34.1 **Upton – large-scale housing estate**

Figure 34.3 The teachers' SuDS session (courtesy University of Northampton)

Figure 34.4 Banner produced to advertise the SuDS Fair (courtesy The Prince's Foundation for Building Community/University of Northampton

- staff from Anglian Water
- four University of Northampton STEM ambassadors
- 20 school staff and over 70 children.

The aims of the STEM event were to raise awareness with the school children regarding:

- how our urban landscapes can cause surface water flooding
- what SuDS are and how they work
- how SuDS can alleviate additional risk of flooding from urban landscapes.

The lesson plan was designed to help the children develop a better understanding of how the water cycle (which they had previously studied) could be linked to flooding in urban developments. It also incorporated how flood risk could be mitigated using SuDS, alongside the biodiversity and green space benefits. The model allowed them to relate the exercise directly to Upton.

The SuDS model was the central focus for the STEM activity, and after the event, the school also used it to engage other children within the school. The model actively demonstrated how water flowed around the buildings and within the landscape, and how parts of the model would flood when it rained (simulated using spray arms). The engineering issues and how SuDS work were then explained, and the children were invited to retrofit the model with more sustainable options to prevent flooding. Green sponges were used to replicate porous surfaces such as grass and green roofs (**Figures 34.1 and 34.2**). Each session was 45 minutes with a group of 10–15 children, repeated throughout the day, and with a group of teachers at the end (**Figure 34.3**).

The STEM activity day developed a legacy of learning at the school, that is being built into the primary school curriculum for future children who will grow up in the Upton area.

Community SuDS Fair

The fair was a broader event, involving a wide range of stakeholders that either provided or participated in the various planned events based at the Elgar Community Centre. These included:

- the Prince's Foundation guided architectural tours
- University of Northampton student ambassadors helped with many tasks throughout the day
- Minilab looking at invertebrates found within the SuDS ponds
- MicroDrainage demonstrating the Upton Meadows SuDS drainage computer model
- "love every drop" activities from Anglian Water
- willow weaving

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CASE STUDY 34.1 **Upton – large-scale housing estate**

- butterfly making with the Bedfordshire, Cambridgeshire and Northamptonshire Wildlife Trust
- bumblebee identification
- Magnus Ramage, chair of the Upton Meadows Residents' Association, hosted the day
- Dairmuid Gavin (garden designer and TV personality), a Prince's Foundation ambassador "untied" one of the three SuDS interpretation boards which had been funded by The Homes and Communities Agency (HCA)
- an information leaflet to explain the SuDS produced by the Prince's Foundation was available.

The event was held on a Saturday in the on-site Elgar Community Centre, and was advertised through the use of banners (**Figure 34.4**), leaflet drops to over 700 houses, posters in the shop, via the staff and children at the school and on social media. The SuDS model was used to explain and demonstrate SuDS, and the day featured a wide range of interactive events around water and biodiversity, provided by the various partners. Over 100 people (residents plus family and friends) attended the event.

The feedback from the day was extremely positive with 100% of respondents confirming that they had enjoyed the day, having learned a lot about SuDS and the broader ecological issues at Upton, as well as having fun.

CASE STUDY 34.2 **Priors Farm, Oakley – small-scale retrofit demonstration project**

Figure 34.5 Public drop-in session (courtesy Illman Young)

Figure 34.6 Exhibition board for drop-in session (courtesy EA)

Priors Farm is a housing estate of just over 300 homes on the edge of Cheltenham, which suffers from surface water flooding (pluvial flooding), as well as surcharging of its combined sewers (sewer flooding), with consequential downstream flooding of the adjacent estate. The surface water flooding is caused by runoff from the adjacent hill.

The Environment Agency (EA) set up the project under their Gloucestershire Green Urban Rivers Project, to develop and implement measures to improve the ecological quality of rivers or "water bodies" as required by the Water Framework Directive (WFD), which have been affected by sewage discharges. This site was selected as a demonstration SuDS retrofit site within Cheltenham Borough, and sought to engage both the council, their social housing providers, Cheltenham Borough Homes and the Guinness Partnership as partners and supporters in the project, alongside potential input or assistance from the Highways Authority and Severn Trent Water.

This project was always seen as the first phase. Future phases are due to be implemented by the borough council in partnership with Gloucestershire County Council and Cheltenham Borough Homes. This will include a further area of public open space, more rain gardens and a surface water planter in one of the roads.

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CASE STUDY 34.2 **Priors Farm, Oakley – small-scale retrofit demonstration project**

Figure 34.7 Information leaflet showing rain garden design options (courtesy EA/Illman Young)

The aspiration for the project was also to inform and promote the delivery of retrofitted SuDS by third parties into the future. It was also hoped that the outputs would inform the green infrastructure plan for the borough.

The stages of engagement for the project are summarised below.

Stage 1 – Initial engagement by the EA

Initial engagement was undertaken by the EA to explain the problem, generate interest and involvement in the project within the estate and to canvass opinion on possible solutions. These were undertaken in three parts:

1. Letter drop to all houses on the estate, explaining the problem and inviting all residents to a public exhibition (**Figures 34.5 and 34.6**).
2. Public exhibition held on a weekend in an open marquee within the site, with exhibition boards explaining the localised flooding issues and the ways in which it could be addressed. Members of the EA were on hand to answer questions and explain the project further. The exhibition included a quiz for children to undertake, related to information on the exhibition boards.
3. Residents were asked to provide their contact details if they would consider being part of the project, and to provide feedback on the alternative ideas presented.

After this initial engagement, a preliminary concept was developed and the EA tendered and appointed a landscape architect and engineer. The proposals considered the potential of all areas of open space within the estate and evaluated every front garden for the potential inclusion of a rain garden. Three separate areas of public open space were considered suitable, along with around 40% of the front gardens (115 no.), and concept plans produced.

Stage 2 – Further engagement by the EA

The EA undertook further engagement to gain local support for the proposed SuDS in the public open space and to generate commitment by householders to a rain garden in their front gardens. House-to-house visits to discuss both the proposals for the public open space and the idea of rain gardens,

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CASE STUDY 34.2 **Priors Farm, Oakley – small-scale retrofit demonstration project**

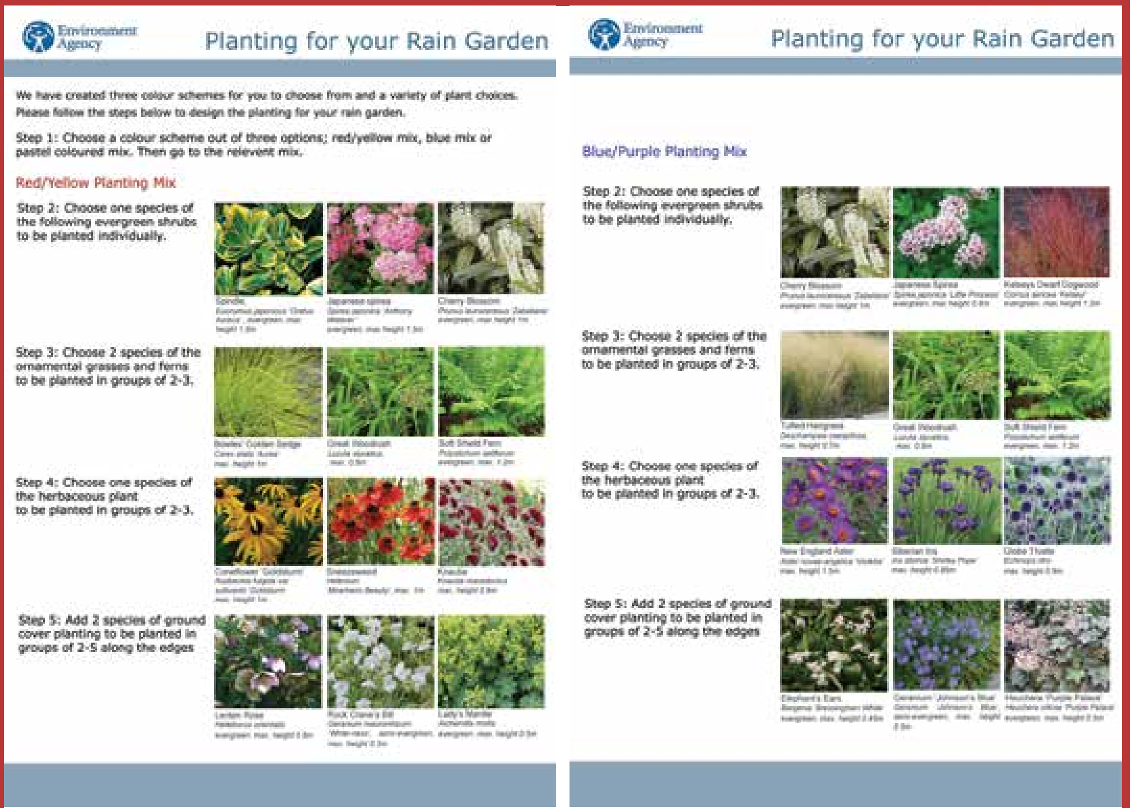

Figure 34.8 Information leaflet showing rain garden planting options (courtesy EA/Illman Young)

focusing on those properties whose gardens had been assessed as being suitable, and those who had specifically expressed interest in being involved.

Stage 3 – Engagement by the landscape architects

The landscape architects then met the individual owners to explain the options for the rain gardens and to agree how theirs would be integrated and planted.

This involved one-to-one meetings with individual residents. Leaflets illustrated the options available for designs and shapes for the rain gardens, with images to explain their "look and feel" (**Figure 34.7**). Residents were asked to select the design they preferred, and to discuss how it would be sited on their property, and the way in which the water would be conveyed to the rain garden from the disconnected downpipe.

Leaflets offering optional colour schemes for the plants were given to those residents who had committed to a rain garden, allowing them to select the individual plant species for their rain garden within a given range of parameters (**Figure 34.8**).

During construction, residents were involved in agreeing how existing plants would be lifted and replanted (where relevant) to make space for the rain garden, any specific details regarding the route of the channel to the rain garden, and how the actual plants would be set out within it.

Stage 4 – Education to provide legacy

Further steps were taken to provide a legacy of the engagement, in order to:

- ensure that individual rain gardens are identified as drainage features
- maintain awareness that the redesign of the public open space creates a drainage feature which has environmental benefits
- maintain awareness that all features should be managed to maintain their hydraulic effectiveness in the long term.

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CASE STUDY 34.2 **Priors Farm, Oakley – small-scale retrofit demonstration project**

Figure 34.9 A completed rain garden (courtesy Illman Young)

Figure 34.10 Priors Farm rain garden roundel (courtesy Illman Young)

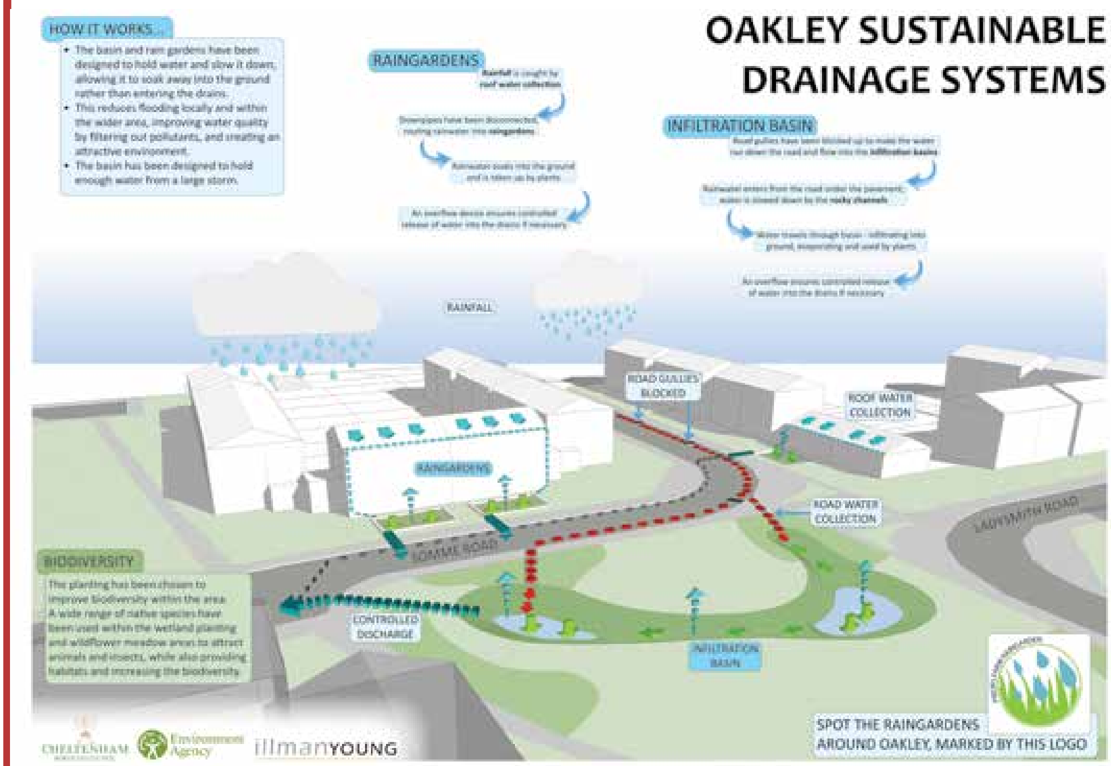

Figure 34.11 Interpretation board for the public open space (courtesy Cheltenham Borough Council/Illman Young)

A Priors Farm rain garden roundel was designed by the landscape architects (**Figure 34.10**), to be installed on each rain garden, and an interpretation board was designed for the main SuDS component in the public open space to explain how it works, and to identify some of the properties that have been retrofitted (**Figure 34.11**).

34.5 REFERENCES

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STATUTES

Acts

Data Protection Act 1998

Image courtesy Studio Engleback

35 COSTS AND BENEFITS

Contents

Chapter 35

Costs and benefits

This chapter provides an overview of key concepts in estimating the costs and benefits of SuDS schemes and how these can be compared. This chapter does not provide unit costs or benefit values.

▶ *Reference is made to several other publications that provide further guidance and tools in Sections 35.3.10, 35.4.7 and 35.5.5.*

35.1 INTRODUCTION

35.1.1 Why assess costs and benefits?

SuDS can deliver multiple benefits (**Chapter 1**), and the overarching principle of SuDS design is that surface water runoff should be managed to maximise these benefits (**Chapter 2**). Achieving this is dependent on good design, good engagement and good decision making.

A vital part of good decision making is the ability to understand both the costs and the benefits associated with the decision being made. This needs to be based on the best evidence available, bearing in mind that the information will never be complete or perfect. Recognising and dealing with uncertainty has always been an intrinsic part of decision making.

Costs, to a larger extent, are relatively straightforward to quantify, but benefits are generally not so easy. However, comparing costs and benefits can prove very worthwhile. For example, although the cost of implementing a SuDS scheme will generally be borne by the developer, in some scenarios it could be shared by other partners where they will benefit, eg a sewerage undertaker, local authority or other interested party.

Many stakeholders can potentially benefit from a SuDS scheme, especially if opportunities are identified at feasibility stage and appropriate engagement is undertaken. As the benefits of SuDS are now better understood, partnerships for delivering schemes are becoming more common. Partnerships have the advantages that there may be (a) more than one source of capital funding and (b) a shared responsibility for long-term costs. Potential partners will want to know how and why they should help with funding and what the benefits will be for them. Details of potential beneficiaries and types of potential funding groups are provided in Digman *et al* (2015).

CASE STUDY 35.1 **Herne Hill and Dulwich flood alleviation scheme**

Figure 35.1 Flooding in Turney Road, 2004 (courtesy Alastair Macdonald, resident)

Figure 35.2 Dulwich Park geocellular storage tank during construction (courtesy Project Team)

This award-winning* public–private partnered scheme used a series of linked SuDS installed in a public park and two private parks in Southwark, London, to alleviate recurrent flooding of homes and businesses along the line of the culverted River Effra.

Figure 35.3 Earth bunds integrated into a new play area (courtesy Project Team)

The scheme was designed and delivered through a partnership between Southwark Council and Thames Water, with support from the Environment Agency (EA), with the £4.28 m costs shared by the Council (5%), Thames Water (54%) and the EA mediated flood defence grant in aid (41%). Thames Water have provided funding to Southwark Council for long-term maintenance. It is one of the first multi-agency SuDS schemes delivered in London and is considered a model scheme for partnership working and multi-agency project delivery. One key success of the project was to align the investment by the Council with the water company's funding cycle for AMP5, with successful delivery by March 2015.

The scheme has a 100-year design life and provides protection from surface water and sewer flooding for 1:75 and 1:30 year events respectively. Overall, 447 properties have a reduced risk of surface water flooding and 80+ properties have a reduced risk of sewer flooding.

The direct economic benefits were valued following guidance provided in EA (2014). These were conservatively valued at around £12.03 m. The SuDS have provided a 2750 m^2 wetland and some 5400 m^2 of new wildflower meadows. There is also a series of new earth bunds that detain, divert and direct flows to storage of 47,000 m^3 on the surface with a further 4000 m^3 in three underground geocellular tanks.

Extensive stakeholder engagement with local residents, businesses and community interest groups was integral to the success of the scheme and ensured a legacy of amenity and environmental benefits for the local community as well as signposting a way forward for future approaches to reducing the risk of surface water flooding in urban areas.

* The ICE Engineering Award winner on 14 May 2015, the EA Project Excellency Award 2015 (partnership category) and shortlisted for the British Construction Industry Awards 2015.

35.1.2 What can be assessed?

Costs are estimated in order to understand one or more of the following:

- the likely capital cost of a proposed scheme
- the likely operation and maintenance costs of a proposed scheme – annually or over the design life of the scheme
- the total cost of a proposed scheme over its lifetime (ie whole-life cost)
- how different elements of the proposed scheme might contribute towards the capital or maintenance costs and, therefore, how costs might be optimised (eg looking at options that reduce long-term maintenance costs)
- where and when costs might accrue to different stakeholders
- how costs of alternative SuDS schemes compare with one another or compare to a conventional piped drainage scheme
- how costs might best be reduced.

In order to understand "the return on the investment" of a scheme (ie how much benefit is gained from the cost incurred), it is also necessary to assess the benefits.

In general terms, benefits can be assessed in order to understand:

- the type and scale of benefits of a proposed scheme
- where and when benefits might accrue to different stakeholders
- how different elements of the proposed scheme contribute towards the delivery of the overall benefits of the scheme and therefore how benefits might best be maximised or optimised
- how benefits of alternative SuDS schemes compare with one another or compare to a conventional piped drainage scheme.

When both the costs and benefits are assessed together, this enables the SuDS design to be optimised (ie to manage, treat and make best use of surface water in order to maximise benefits at reasonable cost) and should form part of the option appraisal process.

Where a comparison is being made between alternative SuDS options or a SuDS scheme is being compared with a below-ground piped drainage system, it is important to ensure that like is being compared with like. For example, either the water quantity and water quality performance of each option has to be identical or the benefits that can be attributed to that performance (such as improved water quality or reduced flood risk) need to be estimated separately for each option.

35.1.3 When should an assessment be carried out?

The usefulness and effectiveness of assessing costs and benefits is greatest when it forms part of an early stage of the design process (**Chapter 7**), so that scheme viability and affordability can be addressed up front. Once the main planning and design decisions have been made for a site, the type of options (decision alternatives) that can be assessed and compared become more limited.

Project partners, clients or funders and other key stakeholders should agree on whether such an assessment is required, why, when and to what level of detail (**Section 35.1.4**), as schemes are usually defined and designed to meet specific objectives (local or national standards, local planning objectives etc).

35.1.4 How can costs and benefits be assessed?

The level of detail appropriate for an assessment will depend greatly on the drivers for the assessment, the scale of the scheme, the extent of the likely benefits that can be realised and what stage of the design process has been reached.

Both costs and benefits are highly context specific and will vary significantly (in monetary terms) depending on the site characteristics, the use(s) of the site and the specific composition of the SuDS scheme.

It is important for any assessment to be robust, transparent and open to scrutiny. This will lead to increased buy-in from stakeholders and more opportunities for shared funding.

The remainder of this chapter provides an overview of key concepts in estimating costs and benefits (**Section 35.2**). Then the chapter summarises best practice for estimating costs (**Section 35.3**) and assessing benefits (**Section 35.4**), and subsequently how costs and benefits can be compared (**Section 35.5**).

This chapter does not provide unit costs or benefit values. Several of the publications listed in this chapter do provide unit costs and/or benefits, but these should be used with caution. These sources of information are often based on studies carried out more than ten years ago or are based on a limited number of case studies, so are likely to be subject to high levels of uncertainty. If using this information, checks are needed to ensure that inflation is accounted for, that the case studies used to generate the unit costs/benefits are representative of the characteristics of the site to be assessed and that there are no specific features of the scheme that are likely to have a significant impact on the cost/benefit. For example, whether or not an impermeable liner is required beneath a detention basin will have a significant impact on cost; whether or not the permanent pond volume (in addition to the attenuation storage volume) is included as part of the volume calculations for a pond component will also have a significant impact on cost.

Defra (2007) and HM Treasury (2011) provide a number of supporting documents for how to assess costs and benefits under the Green Book series. Publications on benefit transfer methods, and the limitations of doing this, are particularly relevant, because SuDS benefits are frequently determined based on transference from seemingly equivalent or comparable schemes. Digman *et al* (2015) provides guidance on how to do this.

There are a number of other publications that provide guidance on estimating costs and benefits relevant for SuDS. These are listed in **Section 35.3.10**.

35.2 KEY CONCEPTS FOR ASSESSING COSTS AND BENEFITS

35.2.1 Whole-life valuation

If whole-life costs and benefits are considered early enough in the development of a scheme (ie at the feasibility stage), this can have a number of advantages. By having an improved understanding of long-term investment requirements (rather than just capital costs), it is also possible to secure:

- more robust decision-making at option appraisal stage
- improved assessment of long-term risks to SuDS scheme performance and inclusion of monitoring and management plans to minimise these risks
- reduced uncertainty associated with adoption agreements and commuted sum contributions.

Whole-life costing (sometimes referred to as life-cycle costing) considers the total cost of a scheme over its lifetime. **Figure 35.4** shows a conceptual schematic of a potential cost profile for a SuDS scheme. This not only covers feasibility studies, site investigation, design and construction, but also includes operation, maintenance, adaptation and (depending on the planning conditions for the site) disposal and decommissioning activities.

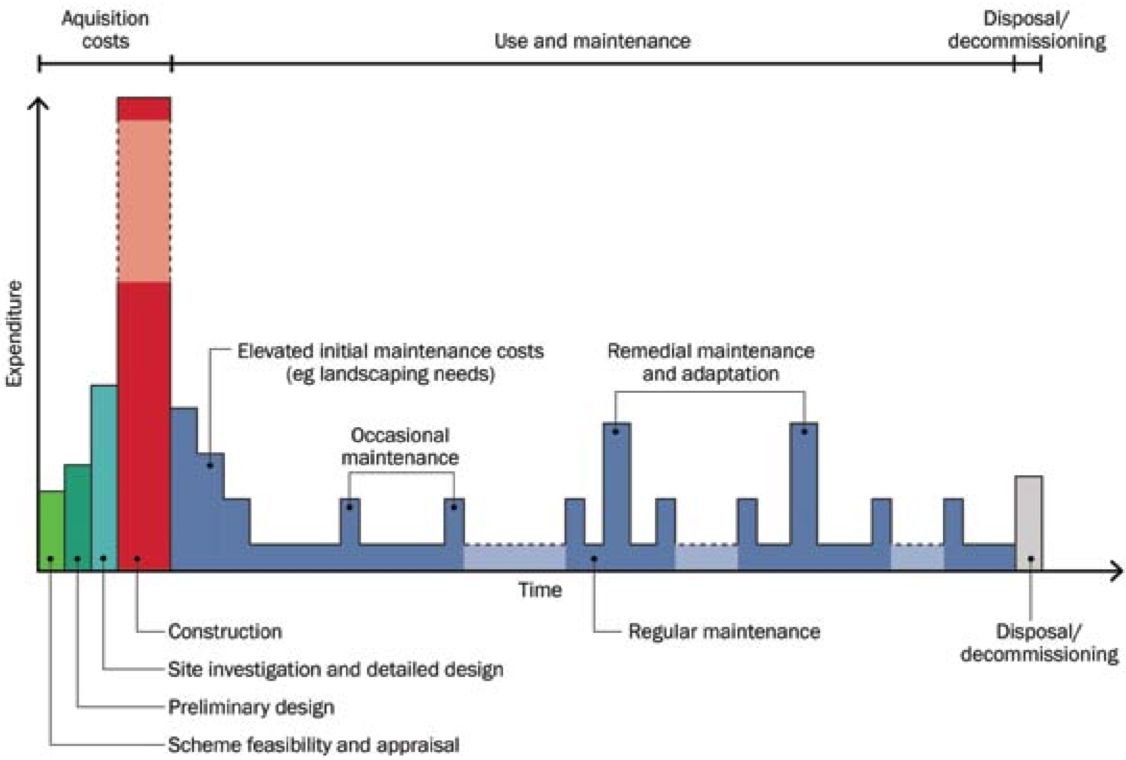

Figure 35.4 An example SuDS expenditure profile

One of the challenges of whole-life costing is determining what the "lifetime" of the scheme will be. The primary purpose of expenditure on a SuDS scheme beyond the construction stage is to maintain the system's performance for its lifetime. Although a scheme may have a specific design life (sometimes referred to as expected effective service life), in reality the life expectancy (or actual service life) for a scheme alters constantly, depending on a number of factors including the maintenance activities (**Section 35.3.3**) that are (or are not) undertaken and any changes in function of the site. With the growing understanding about future changes in climate, and urban design and planning, the required performance of the scheme may also change over its lifetime. Hence, the flexibility to allow change is also an important consideration in scheme selection.

In the same way that costs accrue throughout the lifetime of a SuDS scheme, benefits can also accrue over time; that is, not all benefits may be realised immediately following construction. Therefore, any assessment of benefits also needs to adopt a whole-life evaluation approach. Consistent approaches for both benefits and costs then allow fair comparisons, where this is required. Discounting is described in **Section 35.2.2**.

35.2.2 Discounting

Discounting is the approach used to determine the present day value of future costs to be spent and/or benefits that are predicted to accrue over time. By discounting predicted costs and benefits over the lifetime of a scheme, they can be more appropriately compared. As the value of money changes over time, the value of a cost or benefit in the future may not be representative of its actual worth in present terms. Therefore, a standard accounting technique is to calculate a "present value" (PV). This results in a cost or benefit that occurs in the future being given a lower value than if it occurred now (**Equation 35.1**).

Where there are multiple costs and benefits occurring over multiple years for a scheme, by summing of all of the individual PVs for each cost or benefit for each year, it is possible to determine the "net present value" (NPV) for the scheme as a whole (**Equation 35.1**).

When assessing whole-life costs and benefits, it is advisable to use PVs, but selection of the most appropriate discount rate is very important, as it has a significant effect on the outcome of the analysis.

Calculations using a high discount rate will make future costs less important, while a lower discount rate will reduce the impact of early capital costs on the whole-life cost.

The discount rate should be agreed with the relevant parties in advance.

In the UK, HM Treasury (2011) recommends a discount rate of 3.5%. For schemes with a lifetime of over 30 years, the Treasury recommends that a declining schedule of rates is used rather than the standard discount rate. The rationale for this comes from uncertainty in the more distant future.

Further guidance on using NPV is provided in **Section 35.5.1**.

Commuted sums that are paid by a developer to local authorities for the adoption of SuDS are usually limited to a 25 year period, but can be longer, so the standard discount rate can be applied. However, costlier rehabilitation works that may be required beyond the first 25 years should consider a longer discount period.

EQ. 35.1 **Calculating present value and net present value**

The formula for calculating the present value for a future cost (or benefit) is:

$$PV = \frac{C}{(1+i)^n}$$

where:

n = time horizon in years (ie the number of years from now that the cost occurs)

C = monetary cost (or benefit)

i = discount rate

The formula for calculating the net present value for a scheme is:

$$NPV = \sum_{0}^{t}\left[\frac{(B_t)-(C_t)}{(1+i)^t}\right]$$

where:

B_t = total monetary benefits in each year between zero and the end of life t

C_t = total monetary costs in each year between zero and the end of life t

t = design life or planning period covering the entire life cycle

i = discount rate applied for the year under consideration

35.2.3 Uncertainty and sensitivity analysis

When assessing costs or benefits, it is important to be aware of the uncertainty associated with estimates and to carry out sensitivity analysis where necessary.

There are many sources of potential uncertainty when estimating costs and benefits, although generally these are not specific to SuDS. The sources are very diverse, ranging from the discount rate used to the application of unit costs to the receiving water quality and the future climate. Potential sources of uncertainty when assessing benefits are described in Digman *et al* (2015).

The scale of uncertainty will vary depending on the source data and the method used for the estimation, but it will not always be known. The significance for decision making of the uncertainty related to costs and benefits depends on the characteristics of the site and the proposed scheme.

By undertaking sensitivity analysis it will become apparent which valuations have the greatest effect on determining the most cost-beneficial option and therefore where allowances need to be made to account for uncertainty or, in cases of extreme uncertainty, where that uncertainty needs to be reduced.

In its simplest form, sensitivity analysis can consist of using different values from those used in the initial assessment and seeing what affect this has on the outcome. However, if there are a lot of parameters, sensitivity analysis by varying each parameter in turn can be time consuming. In such circumstances, it is worthwhile looking at available tools for economic appraisal that provide a degree of automation to the process, such as from Digman *et al* (2015).

Sensitivity analysis can also be applied to assessments that do not result in quantification. For example, where stakeholders are involved in a qualitative assessment, they are likely to have different views of what is most important and score benefits differently. Sensitivity analysis can help to determine whether these differences would affect the final decision. Often they do not, and so sensitivity analysis can help to resolve any disagreements between interested parties (Maxwell *et al*, 2011).

Further guidance on dealing with uncertainty and sensitivity testing can be found in HM Treasury (2011), Shamier (2013), DCLG (2009) and Maxwell *et al* (2011), among others.

35.3 ESTIMATING COSTS

35.3.1 Feasibility, appraisal and design costs

Feasibility, appraisal and preliminary design costs can sometimes be greater for SuDS schemes than for below-ground piped drainage systems, as there are more issues to be considered. However, some of these costs may be attributed to landscape and building design. Good SuDS design should look at how to maximise the various benefits offered by SuDS, which may require the appraisal of a range of options. Further details on the planning and design process are provided in **Chapter 7**.

The cost of the land within a site required for the SuDS scheme (known as "land-take") can be one of the most significant factors influencing the cost of implementing a SuDS scheme and therefore should be considered as early as possible. With good design of multi-functional space, the effective cost of the land for a scheme can be minimal, for example where the site has multiple uses such as a car park or recreational area, or where the scheme forms part of a required public open space area. However, in high-density settings the value of land can far outweigh construction costs and the land-take associated with specific SuDS components may determine the selection of drainage options. Whether or not the cost of land should be included within a whole-life cost assessment will depend on whether the use of the land is dedicated to SuDS alone; whether the land can serve multiple functions (because of using SuDS); or whether the land would otherwise be developable if not used for SuDS, that is its value could be realised in another way (**Section 35.3.8**).

35.3.2 Construction costs

Construction costs to be considered in any costing process should include:

- material costs
- land costs
- construction (labour and equipment costs)
- planting and landscaping costs
- erosion and sediment control of the SuDS during construction and any subsequent rehabilitation
- relocation of existing utility assets (if required – generally only for retrofit schemes).

The cost of constructing a SuDS scheme will depend primarily on the size of the contributing catchment area, but will also be influenced by:

- soil type (eg excavation costs are likely to be significantly higher in rocky soils; infiltration opportunities will vary)

- groundwater vulnerability (eg sensitive groundwater zones may require impermeable geomembrane liners to be included within the design)
- design criteria (these will determine component sizes and the extent of Management Train needed)
- design features (eg heavily planted ponds can be more expensive than ponds left to colonise naturally)
- access and space requirements
- location (eg material and labour costs vary regionally, and local rainfall characteristics will affect sizing)
- inlet and outlet hydraulic control characteristics
- any off-site works required for exceedance flow management.

In general, the total volume or area of a SuDS component is likely to be a strong predictor of cost. However, there are economies of scale associated with construction, due to costs of inlet and outlet structures, and mobilisation of equipment that are relatively similar regardless of component size.

As with any drainage scheme, consideration should also be given to the impacts of the scheme during the construction period on the site and the surrounding area (whether these can be monetised or not), such as noise, disruption or inconvenience to residents and others.

Guidance on construction of individual SuDS components is provided in **Chapters 11–23**. Guidance on construction good practice is provided in **Chapter 31**.

When employing a quantity surveyor, it can be helpful to discuss with them how costs for the SuDS components can be determined separately from other external works. For example, there will be a need to differentiate between generic soft landscape works and those that are part of the drainage system works. This will enable correct costing, billing and allocation of maintenance resources.

35.3.3 Operation and maintenance costs

Although the greatest part of the total cost for a scheme is usually the capital cost, SuDS schemes also require a finance stream to cover long-term operation and maintenance costs (as does a below-ground piped system). An estimate has to be made regarding what these costs are likely to be, and funding requirements need to be agreed by the parties involved.

As many SuDS schemes utilise natural planting and are designed to support ecosystems and biodiversity, there needs to be a period of intensive maintenance of the emerging vegetation to ensure that it grows and provides the expected service. This will usually require specialist horticultural expertise and will incur costs beyond the construction phase. It is recommended that this is included in the construction contract and is the responsibility of the contractor (**Chapter 29**). Where the SuDS have more than one use, such as for recreation, there may also be a period of initial setting up and commissioning of the recreational area that will incur costs, although these costs would be expected to accrue to the operators of the recreational facilities rather than the developer.

SuDS schemes then require maintenance, in order to ensure short-term operation and minimise risks to long-term performance.

Operation and maintenance activities can be classified as follows:

- inspection and reporting (eg regular visits which are generally undertaken at the same time as regular maintenance; this may also include monitoring at larger sites, if required)
- regular maintenance (eg clearing inlets and outlets, collecting trash and debris, grass-cutting, vegetation management, brushing of permeable surfaces, emptying of silt traps)
- occasional maintenance (eg responding to problems such as blocked culverts or trash racks, pollution incidents, vegetation death, structural damage, responding and clean-up after extreme events)

- remedial maintenance (eg for major during-life refurbishment such as geotextile replacement, vegetation replacement, soakaway replacement, major sediment removal activities)
- adaptation actions (eg responding to changes in drainage requirements for the site, especially if the life of the SuDS scheme is to be extended, although this can only be costed if planned).

Operation and maintenance costs will normally comprise:

- labour and equipment costs
- material and/or replacement product costs
- replacement and/or extra planting costs
- disposal costs of, for example, contaminated sediments and vegetation (**Chapter 33**).

Where pollution prevention strategies such as street sweeping and public education programmes are included as part of a SuDS scheme (**Chapter 27**), these costs should be included as an continuing operation cost.

The cost of operation and maintenance activities can vary substantially, depending on:

- location (this will influence material, labour and equipment charges)
- ease of access (confined sites can be much more expensive to maintain due to requirements for specialist equipment)
- upstream activities (in particular, any ongoing development, as this will influence the rate of sediment accumulation in the system)
- use of the SuDS (where it is multi-functional, such as an additional amenity or ecological function, specific maintenance may be required to ensure that functionality is maintained, but these costs may be shared between various partners, such as the local authority or volunteer community groups)
- quality of on-site construction or off-site manufacture of products
- the need for off-site disposal of waste
- the effectiveness of the design of the scheme to mitigate the above costs.

Guidance on designing for maintenance for individual SuDS components is provided in **Chapters 11–23**. Guidance on maintenance good practice is provided in **Chapter 32**.

Where SuDS are part of or provide multiple functions, there may be important social considerations and risks associated with their normal functioning. Where, for example, a SuDS component provides a storage area for exceedance flows that functions infrequently and is also used for other purposes, such as recreation, there may be a number of additional costs to consider, such as:

- provision of permanent signage to warn of infrequent inundation of the area
- educating the local community of the function of the SuDS component and encouraging local ownership and appropriate use
- warning the local population when inundation is imminent and erection of temporary warning signs or barriers
- policing the area when the area is inundated, to ensure public safety
- where the design does not provide for it, pumping out and restoration of the temporarily inundated area, including verifying that the ground does not present a health risk
- engagement with local communities before, during and after an inundation event.

Reference should be made to best practice in designing and managing for exceedance as defined in Digman *et al* (2006) and Digman *et al* (2014) and to ISO 31000:2009 for risk assessment and management. These costs will vary depending on local circumstances and the particular use of the land, which may or may not be multi-functional.

35.3.4 Monitoring costs

For large or high risk schemes, the environmental regulator may require a long-term monitoring regime as a condition of planning. At such sites, the capital and ongoing costs for monitoring also need to be included in the economic evaluation.

35.3.5 Disposal and decommissioning

At the end of its design life, it is likely that a SuDS scheme would either be:

a) fully rehabilitated, in which case the cost would be borne by the drainage owner or adoption body, or

b) redeveloped, in which case the disposal and decommissioning costs would be accepted by the next developer.

Such costs will generally be small, due to the landscaped nature of most SuDS schemes and the lack of significant "hard" infrastructure.

35.3.6 Residual value

In a full economic evaluation, the residual value of the drainage system should be included in the analysis. The land occupied by the system could theoretically have residual or "reclaim" value, if the function of the drainage system is no longer required at the end of the design life. However, in reality, the following factors mean that it is more appropriate to assume this value to be low or zero:

1 The land areas are too small and distributed to be of value for alternative use.

2 The land is part of public open space required by planning conditions.

There is a high likelihood that the space will be required to fulfil a drainage function after the allocated design life.

35.3.7 Costs avoided

When the proposed drainage scheme prevents a future cost, this is called an avoided cost (if it is reasonably certain that the cost would have appeared otherwise).

Costs avoided can be a useful means of comparing a SuDS scheme with either an alternative SuDS scheme or with a below-ground piped drainage system. In order to do this, it is important to ensure that like is being compared with like. For example, the total cost of a SuDS scheme should not be compared with only the capital and operational costs of the below-ground piped drainage system, as invariably the SuDS scheme provides much more than just the drainage for the site. The hard and soft landscaping and additional functions provided by the SuDS scheme (such as recreational space or overlying car park) should be compared with the equivalent for the site should a below-ground piped drainage system be used instead. This will identify any costs avoided due to the multi-functionality of the SuDS scheme and the reduced need for kerbing, manholes etc.

35.3.8 Opportunity costs

Opportunity costs can also provide a useful means of comparing alternative drainage schemes, but again, care needs to be taken to ensure that like is being compared with like.

Unlike the costs avoided discussed in **Section 35.3.7**, an opportunity cost is the gain that would be realised by choosing a different course of action. For example, if land was not being used as part of the SuDS scheme, what would it be used for instead and what gain would it bring?

35.3.9 Optimism bias

Optimism bias is a well-known phenomenon whereby project appraisers tend to be over-optimistic about the outcomes from the decisions they make.

HM Treasury (2013) sets out how to compensate for this bias in the estimation of capital costs. Depending on the project type, the range of bias varies. This can be accounted for by either (a) applying a percentage uplift figure to the original cost estimate or (b) identifying the contributory factors that lead to the bias and reducing these, which in turn justifies the percentage uplift to be reduced.

There is no similar specific guidance in the supplementary guide for dealing with optimism bias when estimating operation and maintenance costs or benefits. Sensitivity analysis is recommended instead that enables decision-makers to consider to what extent their decisions would change if the actual cost (or benefit) was significantly greater or less than estimated. For example, how much can maintenance costs increase if the option is to remain worthwhile?

Guidance on the application of this approach to the assessment of SuDS schemes (for both costs and benefits) is provided in Digman *et al* (2015).

35.3.10 Tools and further guidance

Royal Haskoning (2012) provides a literature review of costs and benefits of SuDS in the UK (including available case study evidence), a unit cost database (based on sources used in the literature review) and a review of the cost effectiveness of SuDS.

Guidance by Pittner and Allerton (2009) is supported by a whole life cost and whole life carbon tool (SCOTSNET, 2010) which can be used to support the SuDS selection process for different sites. The tool calculates capital and maintenance costs and in turn calculates the whole life cost of the scheme. It can also calculate whole life carbon.

A simpler, higher level costing tool is available on the UKSuDS website: **www.uksuds.com** (SuDS construction and maintenance cost calculator). This provides indicative costs for different types of SuDS components, but can also be used with site-specific costs input by the user to calculate whole-life costs for a SuDS scheme.

A number of documents are available that provide further data on costs and guidance on their usage, including Kellagher *et al* (2013), Gordon-Walker *et al* (2007), UKWIR (2005) and HR Wallingford (2004). For the most part, these are cited in Royal Haskoning (2012).

There is also a series of Defra case studies looking at comparative costings for surface water sewers and SuDS. Details can be found on: **www.susdrain.org**.

TABLE 35.1 Examples of types of benefits from using SuDS

Benefits provided by SuDS	Aspects of the SuDS design that provide this benefit	Who is likely to benefit?[1]	How soon is the benefit likely to be realised?[2]	Type of benefit[3]			
				Water quantity	Water quality	Amenity	Biodiversity
Air quality	Air particulate filtering via vegetation (eg trees and green roofs)	Community, local authority, environmental regulator	Medium term			✓	
Air and building temperature (thermal comfort and energy savings)	Green and blue spaces, green roofs	Community, businesses	Short term			✓	
Biodiversity and ecology	Habitat creation and enhancement, connecting habitats	Community, environmental regulator, local and national conservation groups, local authority	Medium term				✓
Carbon emission reduction and sequestration	Low energy needs (materials, construction and maintenance), sequestration (eg trees and wetlands)	Developer, community, businesses	Immediate (energy needs) Long term (sequestration)			✓	
Climate resilience	Designing for exceedance, adaptability of scheme; also see air and building temperature, flood risk, groundwater recharge and soil moisture levels, security of water supply, sewerage systems and sewage treatment works available capacity	Community, local authority (and many others depending on the level of climate change experienced in the future and which benefits are affected)	Medium to long term	✓	✓	✓	✓
Community cohesion and crime reduction	See visual character, economic growth/ inward investment and education	Community, local authority, local police force	Medium term			✓	
Economic growth and inward investment (including tourism, productivity and property prices)	See visual character, recreation and air and building temperature	Developer, community, businesses, local authority	Immediate (property prices) Medium term (others)			✓	

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TABLE 35.1 Examples of types of benefits from using SuDS

Benefits provided by SuDS	Aspects of the SuDS design that provide this benefit	Who is likely to benefit?[1]	How soon is the benefit likely to be realised?[2]	Type of benefit[3]			
				Water quantity	Water quality	Amenity	Biodiversity
Education opportunities	Community engagement (before and after construction), legibility, information boards, education programmes, play features	Community, local schools	Immediate (community engagement) Short to medium term (others)			✓	
Flood risk reduction	Peak flow attenuation, volume control	Community, local authority, local flood authority, local emergency services	Short term	✓			
Groundwater and soil moisture recharge	Interception, infiltration, runoff treatment	Water supply company, community	Medium term	✓	✓		
Health and wellbeing	See air quality, air and building temperature, recreation, crime reduction, reduced flood risk (including mental health), plus others to a lesser extent	Community, health authority	Medium to long term			✓	
Noise reduction	Green and blue spaces, green roofs	Community	Short to medium term			✓	
Recreation	Green and blue spaces and play features	Community, local authority	Short term			✓	
Security of water supply	Rainwater harvesting; also see groundwater and soil moisture recharge	Water supply company, Community	Short term	✓		✓	
Sewerage systems and sewage treatment works available capacity (including reduced CSO spills)	Interception and further runoff volume reduction	Sewerage undertaker, community	Short term	✓	✓		
Visual character	Visual enhancement (as part of surface SuDS)	Community, developer, local authority	Short term			✓	
Water quality	Pollution prevention strategies, Interception, runoff treatment	Local authority, drainage board, environmental regulator, rivers and other waterways authorities, community	Short term		✓		

Notes

1 Only the most significant beneficiaries are listed. Actual beneficiaries will depend on the scheme.

2 Immediate = potentially even before the scheme is complete; Short term = within the first 5 years; Medium term = 5–10 years; Long term = 10+ years (Note that these are only indicative and will depend on the scheme.)

3 See **Chapters 3–6** for more detailed descriptions of the types of benefits and how these can be achieved.

35.4 ASSESSING BENEFITS

Table 35.1 provides examples of the types of benefits that can be attributed to SuDS (in alphabetical order, not in order of scale). This table is not comprehensive, but presents the most commonly recognised categories of benefit that can be readily delivered by good SuDS design. See **Chapters 3–6** for further details of how SuDS can deliver these benefits, and Digman *et al* (2015).

Included in **Table 35.1** is an indication of who is likely to benefit, and an estimation of when these benefits are likely to be realised. This shows that the local community is always likely to benefit.

The table also gives an indication of when these benefits are likely to be realised. These are only indicative and will vary significantly depending on the scheme. However, it demonstrates that some benefits can be realised even before the scheme is complete and the drainage system has been commissioned, such as property prices and educational opportunities. Many benefits are realised in the short term, such as flood risk reduction and improved security of water supply, and can benefit a large number of organisations. Other benefits may not be realised until the medium (5–10 years) or long term (10+ years) and the scale of benefit may depend on other factors such as how much the climate changes in the future (**Section 35.4.6**).

35.4.1 Direct and indirect benefits

Some benefits are a direct consequence of SuDS, such as reduced flood risk (by delivering water quantity criterion 2, **Chapter 3**) or improved biodiversity (by delivering biodiversity criteria 1–4, **Chapter 6**).

However, the overall benefits of a SuDS scheme are more than simply the direct benefits resulting from delivering the design criteria. Many benefits are indirect (sometimes referred to as secondary or incidental benefits) and come about in addition to the main reasons for using SuDS, such as health and wellbeing, which is a product of improved air quality, thermal comfort, recreation etc.

Climate resilience is a combination of both direct and indirect benefits, as the ability of the SuDS to cope with more frequent or more severe rainfall is a direct benefit, for example, but improved regulation of air and building temperatures, improved security of water supply, flood risk reduction etc all contribute to the improved resilience to the present day and future climate as well as being direct benefits in their own right. Because of these relationships and the difficulties of distinguishing which aspects of SuDS provide which benefits, care needs to be taken to avoid double counting of the value of the benefits (**Section 35.4.5**).

One approach that has particular value when the relationships between direct and indirect benefits are complex, but potentially significant for determining overall benefit, is to consider “impact pathways” (Defra, 2007). An example of an impact pathway is shown in **Figure 35.5**.

Figure 35.5 Impact pathway for assessing the benefits of flood risk reduction

35.4.2 Quantifiable benefits

Direct and indirect benefits (as described above) should not be confused with those benefits that can or cannot be quantified.

Some benefits of SuDS are readily quantifiable: for example, where flooding is mitigated the reduced damage can be costed using standardised information, such as Penning-Rowsell *et al* (2013).

Some benefits are not so readily quantified, especially in monetary terms, but this does not lessen their importance and they should not be ignored simply because they cannot be easily costed.

Understanding benefits and methods for estimating their monetary value is still developing. Advances in areas relevant to SuDS, such as the value of ecosystem services, are now providing key benefit valuation information that is being used in tools such Digman *et al* (2015) (**Section 35.4.7**).

In some cases, valuation of benefits can be undertaken using a preference-based approach, such as "willingness to pay" as described in **Box 35.1**.

BOX 35.1 **Examples of methods for quantifying benefits**

Contingent valuation (or willingness to pay)

The contingent valuation (CV) method, using sample evidence from questionnaires and surveys, estimates how much people would be willing to pay for specific environmental or social benefits. In some cases, people are asked for the amount of compensation they would be willing to accept to give up specific benefits. The term "contingent" valuation reflects that people are asked to state their willingness to pay, contingent on a specific hypothetical scenario and description of the environmental service. Water service providers in England use such methods to determine customer priorities for asset investments in their five-year plans.

Benefit transfer

To carry out a CV study requires a significant investment in time and resources. Sometimes this is not feasible or not considered the best use of resources. An increasing number of studies carried out in the UK (eg to value water quality improvements, the benefits of reduced air pollution and the value of ecologically important species) make use of other CV studies using a benefit transfer (or value transfer) approach. This adjusts the values found from other studies by taking into account the characteristics of the study area, and can be a good indication of the range of possible values that might be expected from a full CV study.

Shamier (2013) provides guidance on this for river basin management planning, which can also be applied to SuDS. The UK Government also has guidelines for valuing environmental impacts using value transfer in appraisals (Eftec, 2010).

Hedonic pricing

Hedonic pricing is a method used in a number of benefit valuations. It relies on indirect information, such as that provided by households when they make their property purchase location decisions. Higher housing prices and lower wages reveal how much people are willing to pay for the amenities in desirable locations and the added value that SuDS provide is reflected in this.

In one USA study (Johnstone *et al*, 2006) the improvements to water quality due to SuDS was estimated by hedonic pricing as adding some 5% to the value of undeveloped riverside properties and some 10–15% for developed riverside residential properties. A study in Denmark (Zhou *et al*, 2013) estimated by hedonic pricing that property values reduced by 1.7% for every 1% increase in distance to local lakes (whether or not these were integrated into a green area).

35.4.3 Non-quantifiable benefits

Where benefits cannot be quantified in monetary terms, these can still be assessed in a qualitative way. The extent to which this is necessary (ie would consideration of these benefits influence the decision making?) and how this is done needs to be agreed by the partners involved in making the decision. Often this is by negotiation, as various criteria (or benefits) may be of a greater or lesser importance to the various parties involved.

As many of the benefits will be provided to the local community, community engagement exercises can provide useful information for a qualitative assessment. For example, the community could be asked questions such as "How much more outdoor activity do you think you would do if you had more public green space?"

At its simplest level, a qualitative assessment can compare the relative scale of benefits, such as:

1 no added benefit
2 some benefit
3 medium benefit
4 significant benefit.

Qualitative assessments like this need to be considered separately in the decision-making process from the quantitative outcomes described above.

However, in cases where some (but not all) of the benefits can be directly monetised, a qualitative assessment can act as the starting point for quantifying the remaining benefits by providing "switching" or "implied" monetary values. This becomes a worthwhile exercise where the non-monetised benefits have a score of 3 or 4 based on the scale given above.

For example, where the monetised benefits amount to say, £9 m for a scheme costing £10 m, the non-monetised benefits would need to have an implied value of at least £1 m to have a positive benefit–cost ratio (**Section 35.5.2**).

Alternatively, the monetised benefits can be used as a benchmark for benefits that are not directly quantifiable. For example, stakeholder engagement can be used to score and weight non-monetised benefits against benefits that have been monetised and provide an estimated "implied" monetary value (**Section 35.5.1**). This process should include sensitivity analysis to check the relative significance of the results from the scoring and weighting exercise, and any other assumptions used. An appropriate uncertainty range can then be applied to the resultant estimations.

This process is most worthwhile if the non-monetised benefits are likely to have a significant effect on the determination of the preferred option. Depending on the information readily available for quantifying some benefits, it can also be a less costly alternative to using contingent valuation, benefit transfer etc methods (**Box 35.2**) or can be used to validate the results from these methods (Penning-Rowsell *et al*, 2013).

Some benefits are sometimes deemed as inappropriate to monetise, depending on the purpose of the analysis and with whom it will be communicated, in which case a cost-effectiveness analysis approach can be adopted (**Section 35.5.3**).

35.4.4 Benefit attribution

Although there are many potential benefits provided by SuDS, these do not necessarily only come about by delivering a SuDS scheme. For example, green areas alone can provide a number of the benefits, even where SuDS are not included in these areas, such as recreational space and urban heat island mitigation. It is therefore important that benefits are attributed correctly and only to where they are provided by SuDS components alone, especially if comparing development options with and without SuDS.

35.4.5 Double counting

There are two main potential sources of double counting when estimating benefits:

1 overlap between benefit categories (**Table 35.1**) and/or using the same population for different benefit categories, such as for both recreation and health and wellbeing
2 using benefit transfer values or similar (**Box 35.2**) that include more than just the specific benefit being valued

These need to be taken into consideration when identifying which benefits are going to be assessed and the best estimation method to adopt. All assumptions should be made clear, along with the implications of these assumptions.

35.4.6 Timing and scaling benefits

The timing and physical scale of SuDS use is important in assessing relative benefits. The benefits provided by an individual component, such as a tree pit, cannot be assumed to be linearly scalable upward where larger or multiple components are being used. This is especially true where biodiversity is considered, as interconnectedness of green spaces is a major determining factor in supporting ecosystems. Therefore, where there is a gradual implementation of green SuDS over time and space, there may be a step change in benefits when these reach a particular level of interconnectedness.

Also, the future is unknown and, therefore, the future benefits that are realised may not be as anticipated. In other words, in the future, one or more of the expected benefits considered valuable today may become less or more important in response to changes in circumstances (whether economic, social or environmental). The most "flexible" option is the option that can still provide benefit value even under future changes.

Guidance on how to include timescales and flexibility in benefit assessment is included in Digman *et al* (2015).

35.4.7 Tools and further guidance

Royal Haskoning (2012) provides a literature review of costs and benefits of SuDS in the UK (including available case study evidence), but information on the monetary value of benefits is limited.

A detailed description of the multiple benefits of SuDS is provided in Digman *et al* (2015), together with recommendations for considering temporal and spatial scales and uncertainties.

Digman *et al* (2015) provides a freely available spreadsheet tool designed for those interested in assessing SuDS benefits. This tool, together with its accompanying guidance, enables a wide range of financial, social and environmental benefits of SuDS to be captured and included in decision-making for drainage infrastructure investments. The tool provides a practical means of assessing and, where feasible, monetising the multiple benefits of SuDS schemes (from small to large schemes). The tool enables alternative SuDS designs to be compared with each other or to a conventional drainage design or any base case.

The tool includes 20 benefit categories, of which the monetary value can be assessed for 18 of these. A database of monetary values is included, although locally derived values should be used as far as practicable.

Jayasooriya and Ng (2014) provide an international review of other available tools for assessing costs and benefits related to SuDS.

35.5 COMPARING COSTS AND BENEFITS

In order to carry out an assessment that compares costs and benefits, it is important to consider whole-life costs (**Section 35.2.1**) based on appropriate discounting (**Section 35.2.2**), and it is also important to consider the benefits alongside costs in a way that they can be readily compared (economic or multi-criteria analysis).

Each of the partners in a scheme may take a different approach to economic analysis (in some cases due to regulatory regime requirements) and it is therefore important to establish from the outset how the economic assessment will be carried out. There are no regulatory standards for economic analysis for SuDS, rather there are standards set out for the various interested parties (eg the Environment Agency for river basin management planning or water service providers for asset management), each of which will need to be satisfied if their organisation is to be a partner in a particular scheme.

Some of the most common methods are described below. These are often used in combination in scheme appraisals.

CASE STUDY 35.2 Application of the BeST tool to compare the benefits of different drainage options (courtesy Yorkshire Water)

Yorkshire Water investigated the potential of different options to reduce CSO spills in Roundhay Park in Leeds, as part of the Periodic Review 14 planning work. This included assessing the benefits of the options using an ecosystem services approach. See Digman *et al* (2015).

Four options were considered, using a range of conventional drainage and SuDS approaches. **Table 35.2** summarises the options and the range of expected benefits associated with each.

- **Option 1:** a conventional solution to store water in tanks at CSOs to limit the volume spilling
- **Option 2:** a conventional option that also solves predicted flooding in the catchment (giving similar hydraulic performance in the combined sewer network as in options 3 and 4)
- **Option 3:** a SuDS approach in public areas to disconnect surface water from the combined system and pass it through the conveyance and storage SuDS
- **Option 4:** as option 3 with measures added in residential private locations

Table 35.2 Summary of range of options and associated benefits

Option summary	Cultural		Regulating				Provisioning	Supporting
	Recreation	Amenity	Flooding and climate resilience	Carbon reduction	Water quality	Flooding	Treating wastewater	Biodiversity and ecology
Option 1: Conventional			×	×	✓		×	
Option 2: Conventional+			×	×	✓	✓	×	
Option 3: Public SuDS	✓	✓	✓	✓	✓	✓	✓	✓
Option 4: Public–Private SuDS	✓	✓	✓	✓	✓	✓	✓	✓

Key
× indicates a negative impact, ✓ indicates a positive impact.

A comparison of the costs and benefits (**Figure 35.6**) shows how the different options are associated with a big range in net present value. **Option 1** reduced the CSO spills but offered no other benefits. **Option 2** provided similar levels of drainage performance in the sewer network to **Options 3** and **4**, but created less benefit having underground infrastructure, and was also less resilient to climate change. **Options 3** and **4** included distributed SuDS features across the catchment, creating a second drainage network to manage surface water, in turn creating wider benefits to the community and environment with similar costs and benefits. Overall, the public SuDS option generated a positive NPV (benefits greater than costs).

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CASE STUDY 35.2 **Application of the BeST tool to compare the benefits of different drainage options (courtesy Yorkshire Water)**

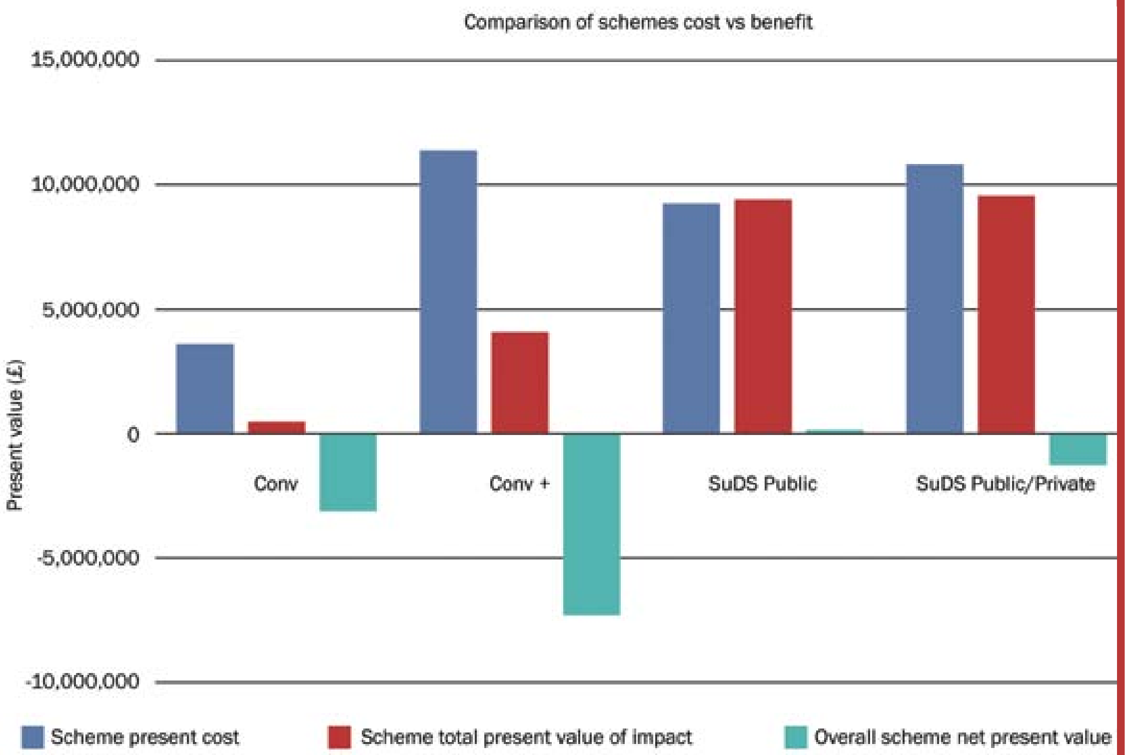

Figure 35.6 Comparison of options: costs vs benefits

35.5.1 Net present value

The net present value (NPV) of a scheme (ie calculating the total value of the scheme in terms of costs and benefits over its lifetime – **Box 35.1**) can be used as a means to compare the overall value of a SuDS design compared with a conventional piped drainage scheme or to identify which SuDS design offers the best value for money.

The process for determining the NPV of a scheme is illustrated in **Figure 35.7**. Where all benefits can be monetised (**Section 35.4.2**), this is a relatively straightforward process (**Figure 35.7a**).

Where some benefits cannot be monetised, these can be "implied" by assessing their likely value compared to the benefits that can be directly monetised (**Section 35.4.3 and Figure 35.7b**).

Care also needs to be taken to ensure that when options are being compared that appropriate consideration is given to:

- benefit attribution (**Section 35.4.4**) and the fact that different options will have different groups of benefits
- timing and scaling of benefits (**Section 35.4.6**).

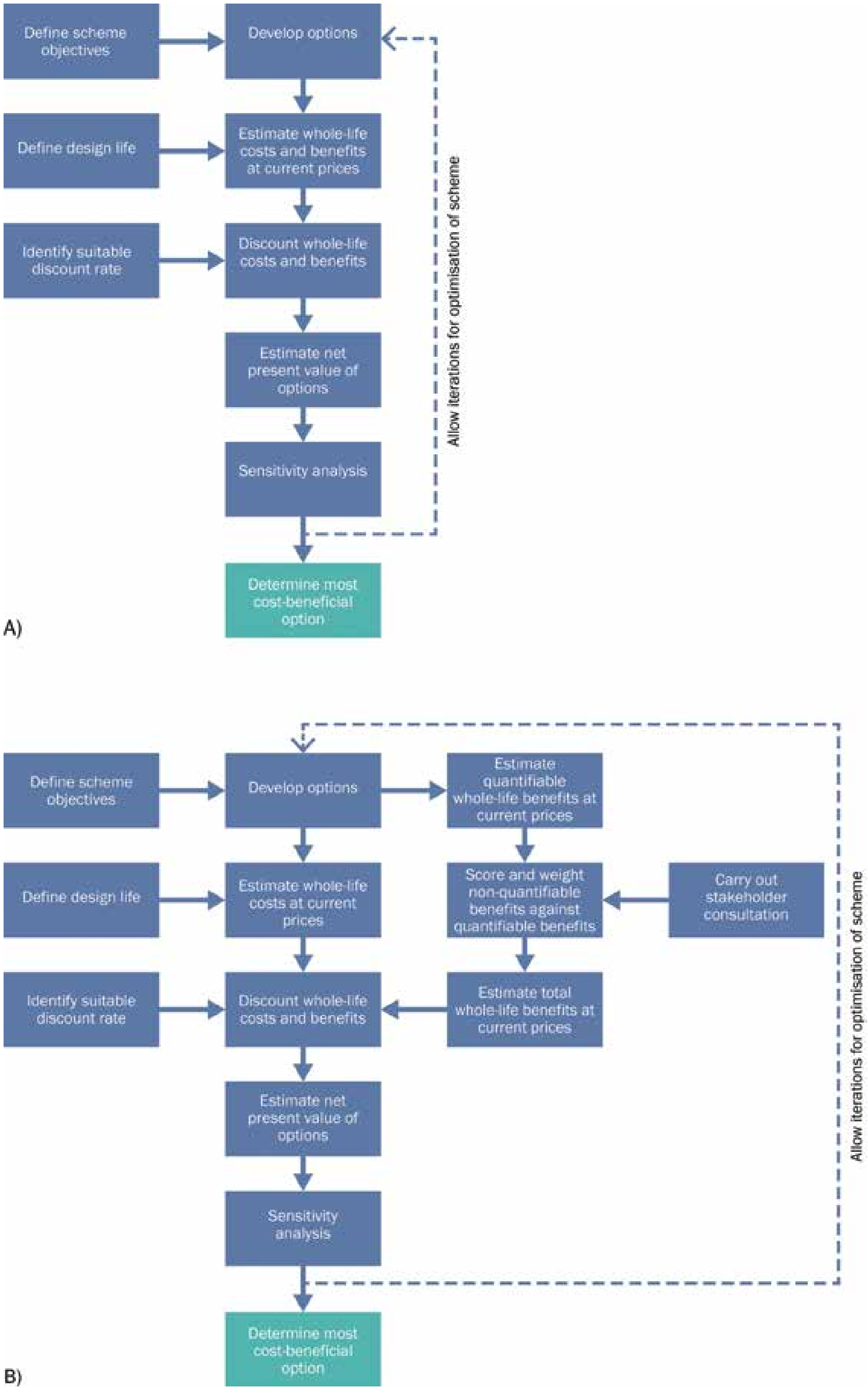

Figure 35.7 Process for estimating NPV (A) where all benefits can be directly monetised, and (B) where some benefits cannot be directly monetised

35.5.2 Benefit–cost ratio

The benefit–cost ratio (BCR) is the ratio between the benefits and costs for a scheme can be used to determine whether it is value for money. This type of analysis does require all costs and benefits to be quantified (whether directly or implied), as per the NPV analysis.

The benefits included in the assessment need to be agreed and applied consistently, if different schemes are being compared, but importantly they can be multiple in nature. For example, a benefit to cost ratio (BCR) of 8:1 has been applied to flood defence related decision-making in England for a number of years. In this instance, benefits include wider considerations, including cultural services as part of ecosystem services valuation (ie it is not just about flood defence – see Eftec, 2010).

35.5.3 Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a form of economic analysis that compares the relative cost to benefit, sometimes described as the change in outcome for a unit of investment. For example, "What is the reduction in flooding as a result of a unit increase in storage volume?" This is typically used where there is only a single criterion (or benefit) being measured.

This type of analysis may be particularly helpful when considering the incremental increase in benefit value over time, for example, the impact of street tree growth on the gradual improvement in air quality.

35.5.4 Multi-criteria analysis

Multi-criteria analysis (MCA) is an umbrella term used for applying non-quantitative assessment techniques (alongside quantitative results where available), where stakeholders believe that there are significant benefits beyond those that can be monetised, and these should be included in the decision-making process.

MCA provides an open and explicit way of presenting monetised and non-monetised impacts of a scheme (ie costs and benefits) to decision-makers, which has a number of advantages over informal judgement. These include the provision of an audit trail, a useful means of communicating complex ideas, scores and weights that can be compared with other studies (to improve confidence) and the possibility of applying sensitivity testing.

35.5.5 Tools and further guidance

Many of the concepts introduced in this chapter are discussed in more detail in Penning-Rowsell *et al* (2013). This document (known as the Multi-Coloured Manual) presents a range of techniques and data that can be used in a practical way to assess costs and benefits related to flood risk management and coastal erosion. The techniques and much of the data is equally relevant to SuDS. The manual also provides details of the derivation of the data presented and the limitations of benefit–cost analysis. Complementary to this manual is a handbook that provides a step-by-step guide to assessing benefits, which is available online (Penning-Rowsell *et al*, 2015).

DCLG (2009) provides useful (relatively non-technical) guidance on BCR, CEA and MCA techniques, and Maxwell *et al* (2011) provides guidance on MCA specifically focusing on social impacts and wellbeing.

Digman *et al* (2015) allows both financial (eg capital equipment, operating expenditure and opportunity cost of providing land for SuDS) and other costs (eg social or environmental costs such as embodied carbon in materials) for SuDS options to be compared with their benefits (see the case study above).

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STATUTES

International Standards

ISO – 31000:2009 *Risk management – Principles and guidelines*

Image courtesy R Nowell

36 HEALTH AND SAFETY

Contents

Chapter 36

Health and safety

This chapter provides guidance on health and safety principles and practices relevant to SuDS. The chapter is intended to provide guidance to designers, drainage approval and adoption bodies, and the public on health and safety aspects associated with SuDS, including:

- *balancing the benefits of SuDS with any potential health and safety risks*
- *good practice design approaches and principles to support the appropriate management of risk to low levels*
- *background information to allow drainage approval bodies to be confident that drainage assets will not pose a liability in either the short or long term*
- *health and safety risk assessment of schemes in-line with BS EN 31010:2010.*

▶ *The guidance in this chapter is supported by the health and safety risk management checklist included in Appendix B.*

36.1 INTRODUCTION

36.1.1 Why should health and safety be considered?

The planning, design, construction and management of sustainable drainage systems falls under the requirements of the Construction, Design and Management (CDM) Regulations 2015. This and other relevant regulations and legislation are presented in **Section 36.5**. This chapter can be used in helping to ensure that SuDS designs fulfil regulatory and legal requirements, and SuDS health and safety risk assessments are in line with BS EN 31010:2010.

This chapter only covers specific health and safety issues relating to the provision of open water components (both permanent and temporary) as part of SuDS. It does not cover general issues and regulation associated with standard health and safety at work principles and conventional drainage design (eg confined spaces – although these are discussed briefly for completeness). Also, it does not cover issues such as highway safety audits that may include some parts of a SuDS scheme (eg permeable pavements or swales adjacent to highways).

36.1.2 When should health and safety be considered?

The SuDS designer has a responsibility to address health and safety under CDM 2015, and must demonstrate this. Health and safety assessment will be a continuous process; it does not just stop once the boxes are ticked. It should be discussed, and principles agreed, at conceptual and outline design stages as part of the CDM designer's risk assessment process. The risk assessment should then be developed and reviewed at all stages of design, construction and maintenance.

A health and safety assessment should be undertaken by the organisation approving the drainage (drainage approving body) when assessing the design of a SuDS scheme. It should also be reviewed following construction and also on a regular basis during operation. The review should consider any changes that have been made to the approved design during construction or operation (see HSE, 2015).

36.2 SUDS HEALTH AND SAFETY: THE CONTEXT

SuDS aim to manage the runoff from development sites, following rainfall, in a way that:

- mimics natural drainage processes
- minimises negative impacts on the natural environment
- reduces the risks of flooding both on site and downstream
- supports the adaptability of the development to the negative effects of climate change
- provides amenity, biodiversity and educational value for the site.

Well-designed SuDS components include features that are no more hazardous than those found in the existing urban landscape, for example ponds in parks. Where communities understand and support the above principles and values, then it is reasonable to expect them to embrace the improved landscape and respond to such hazards in a positive, reasonable and responsible manner.

36.2.1 Balancing risks and benefits

It is important to recognise the inherent tension between the individual leisure user and the various permission givers, regulators and duty holders. Leisure, by definition, is to be free from drudgery, to enjoy freedoms, to play and relax. Consumed (ie paid for) leisure can trigger regulations, imposing qualified duties to manage risk.

An undesirable result can be the duty holder adopting an overly paternalistic approach, resulting from a complex mix of misunderstanding, fear of prosecution or liability to negligence, or as a proxy for other concerns such as a lack of resources and desire for privacy.

Counter-intuitively, the key to challenging risk aversion is the application of balanced risk assessment. There is a need to accept that uncertainty is inherent in adventure and this contains the possibility of adverse outcomes. The Royal Society for the Prevention of Accidents (RoSPA) sums up this approach as follows: “We must try to make life as safe as necessary, not as safe as possible.”

When dealing with the design of public amenity space, it is important to weigh up the risk of harm against the benefits of provision, that is with the objective of balancing positive attributes against the inevitable risk of injury which any public activity generates (Ball and Ball-King, 2011). Publicly accessible green and blue infrastructure (including SuDS) supports important societal benefits including health and wellbeing benefits relating to improved quality of life, and recreational and educational benefits for children and adults.

As a society, we are prepared to broadly tolerate the risks posed by our road network, because of the benefits and support it provides to our daily lifestyle. SuDS components that are on the surface (eg ponds, basins, swales), if managed correctly and if the public are made aware of the risks, should come to be accepted as important, necessary and beneficial ways of managing our societal impacts.

The benefits of providing a well-designed SuDS scheme are local and regional. The risks that need to be considered should look at the local and regional situation and expectations, and balance these risks appropriately.

36.2.2 Managing and informing public perception

The perception of SuDS, and in particular components that comprise bodies of open water, is important as a driver for setting appropriate risk management principles.

A survey of residents living in areas with SuDS ponds was undertaken in 2002/3 (HR Wallingford, 2003). The study confirmed the following:

- The level of education about sustainable water management, and SuDS in particular, was an important factor to the perceived level of risk posed by the drainage system. Informed residents tended to be much more positive than residents whose knowledge about the function of their local SuDS scheme was non-existent or poor.

- Natural aesthetics were shown to play an extremely important role in formulating public attitudes. The more aesthetically pleasing the SuDS pond and the more natural it looked, the more it tended to be welcomed by a community and the lower the importance attached to health and safety risks.
- The effectiveness of the maintenance schedule (in particular relating to litter, pollution and silt accumulation) was crucial in determining the community view of the system.
- In general, the community valued SuDS ponds and felt that they added value to the area and to their homes. The majority of those interviewed would prefer the pond to remain, irrespective of any concerns they might have.

The main concerns about SuDS ponds were related to health and safety risks, and this outcome was confirmed by a more recent study (Bastien *et al*, 2011).

Both studies confirmed that public education and good design and maintenance are crucial in managing and addressing perceived risks. Education strategies should cover:

- the functionality of the surface water management system – where the water flows, where and why it is stored, where it is released to, what would happen if it wasn't there, how it will operate and how it is likely to look in different seasons
- the benefits afforded to the local community and wider society by the SuDS scheme, including children's education opportunities
- the design measures in place to mitigate health and safety risks
- how and when the system is maintained
- the actions that the local community and amenity users should take to further minimise health and safety risks (including effective litter control)
- contact information if a health and safety or maintenance concern is identified.

Also, to allay concerns about open water, it should be clear to those using the surrounding amenity space why it is important to manage and treat the runoff from our development areas and how it is collected and stored. All flow and volume control components should be designed and operate in a predictable and safe manner.

36.3 EFFECTIVE HEALTH AND SAFETY RISK MANAGEMENT

36.3.1 The principles

Competent, best practice SuDS design should mean that health and safety risks are considered throughout the design process. The results should be that risks are reduced to acceptable levels by designing out hazards. The following sections summarise the key best practice SuDS design principles that support the appropriate management and mitigation of risk. They are part of the standard SuDS design practice recommended in the individual technical component chapters and are provided here for completeness. The sections relate to the mitigation of risk related to specific potential hazards. All the recommendations in this chapter should be confirmed as appropriate through site-specific risk assessment.

36.3.2 Drowning risk management

Drowning can occur in permanent bodies of water or in normally dry areas when they contain water temporarily during and after rainfall events. Drowning more frequently occurs from accidentally falling in rather than by deliberately accessing a body of water and then getting into difficulty. The risk may be increased during the hours of darkness and when there is unsupervised access to open water, particularly by younger children or those under the influence of alcohol or drugs.

The risk of drowning is also exacerbated when features such as steep banks, deep bankside or water-edge silt and/or overhanging branches are present. Fast flowing water or areas that become inundated very quickly with a rapid rise in water level may also increase the risk of drowning. Such hazards should always be avoided in SuDS designs.

In 2011, there were 407 reported cases of drowning. Of these deaths, 22 were recorded as occurring in ponds or ditches/burns. The best available information suggests that three hospitalisations occur for every death.

Drowning of very young children is obviously a significant concern. The latest statistics for drowning in the UK show that, of the 0–4-year-old children drowned, the majority were walking or running next to water, rather than being involved in a water-based activity (NWSF, 2012).

In practice, a variety of risk controls will likely be implemented. The exact controls will, of course, be site specific. In many cases simple controls will ensure that the hazards are easy to recognise, avoid and do not pose a significant risk.

Fencing

It is not reasonable, practical or desirable to attempt to prevent drowning by denying access to every piece of water across the UK. Fencing may be an effective but comparatively expensive option which does not remove all the risks arising from water.

The early response to water features in the landscape was to deny access through metal fencing, hedging and planting barriers. However, although physical barriers might be suitable where the risks are high, the provision of pedestrian fencing is frequently challenged by designers, health and safety experts and often by the local community itself. Barriers can prevent or obstruct visual observance of the water body, and the provision of help in an emergency.

Where the water is accessible, the edge gradient above and below the water line, and the depth profile of the water are of critical importance (see **Access to the water**).

If the risk is high, either due to the required nature of the edge, the hinterland activity or a combination of the two then fencing may be deemed necessary. The height and nature of the fence along with location in relation to the water feature are important considerations. At lower risk sites the function of a barrier may be merely to deflect the public from the water's edge. At particularly sensitive locations, such as pinch points or where water is deeper, more substantial fencing may be required.

Where it is considered likely that unsupervised young children could gain access to the water, then a toddler-proof fence 600–750 mm high should be provided to prevent toddlers getting to the water but allow adult entry to step across when necessary. The fence should be a vertical pale type rather than horizontal rail construction which could be used as a climbing frame.

Where fences are provided, full responsibility for maintenance must be established to ensure that liability risks are minimised.

If fencing is not appropriate, different types of planting at the margin can provide an element of physical protection and create a clearly identifiable visual border. If it is not possible to provide a planted margin then clear identification of the edge of the water can be beneficial.

Siting

Careful consideration as to the positioning and design of a SuDS pond is important in terms of minimising misuse and vandalism, and increasing natural surveillance.

An open and accessible situation with local roads, footpaths and houses providing a high degree of natural surveillance from surrounding properties and residents will serve to reduce risks and maximise potential amenity benefits.

Access to the water

Where the water is accessible, the edge gradient above and below the water line and the depth profile of the water are important. In many situations, paddling in the water would be considered acceptable and safe. However, swimming in SuDS components should be actively discouraged. A safe approach is to design the edge of the permanent or temporary body of water with:

1. a "dry bench" before the component to provide a level surface for an individual to assess the surroundings; this could be designed with a reverse slope to stop anyone slipping or riding unhindered into the water
2. all slopes (where people have direct access) not greater than 1 in 3, to allow unaided movement in either direction for able-bodied visitors or maintenance personnel to mow and clear vegetation
3. a level "wet bench" at or just below the normal water surface level which will be both clearly wet and uncomfortable underfoot for anyone who has accessed the water body; this may dry out occasionally in exceptionally dry periods but by and large will remain boggy; the appropriate width of this bench will be dependent on the size of the water body, but a reasonable minimum is considered to be 1.5 m
4. clear identification of the water edge, for example using planting or soft or hard edging (where appropriate).

Access to the water can be discouraged where appropriate through the use of:

- shallow, muddy margins
- reeds and shrubs that do not obstruct visibility, but provide a safe deterrent and barrier to paddling and swimming.

It is important that barrier planting does not obstruct visibility of the water from the surrounding area.

An appropriate maintenance strategy for the bank edges of the water body should be established to ensure long-term public safety.

Consideration should be given to the structure's intended use, the local profile and the needs of residents in terms of things like lighting, disabled access, visibility of waterside edges, changes in levels, as is appropriate for the location and the requirements of the Disability Discrimination Act 1995 and associated duties.

Water body and flood exceedance storage or conveyance design

Most SuDS designs should not be using components close to houses or other buildings where normal still water depths are greater than 600 mm, or normal velocities are greater than 0.5 m/s.

Where deeper and larger components are required, such as regional water features in recreational areas or parks, it is recommended that a level bench should be provided at a depth of 0.6 m before descent to a maximum depth of 1.5 m, at a maximum gradient of 1 in 2.5. It is considered that a reasonable minimum width is 1.5 m. Where practicable, shallower gradients should be considered to suit the surface area of the pond.

Water velocities in SuDS should not be high if an efficient drainage scheme using source control in sub-catchments is provided. The maximum water velocity in an open component should be low enough so that if anyone inadvertently enters the water's edge they can remain standing. The same principle should be applied to flood flows for events up to the 1:100 year (1% annual probability of occurrence) or 1:200 year event (0.5% annual probability of occurrence), where floodwater may be conveyed and stored in exceedance zones.

Table 36.1 gives an interpretation of the guidance provided by Defra (2006) for SuDS application.

TABLE 36.1 Recommended depths and velocities for SuDS and exceedance flow routes

Maximum velocity (m/s)	Depth (m)	Comments
0–0.4	< 1.5	Level benches recommended: ▪ at or just below the water surface ▪ at a depth of 600 m
0.5–0.9	< 0.6	Level bench recommended: ▪ at or just below the water surface
1.0–2.0	< 0.3	

Note that this applies to accessible SuDS or the edges of regional ponds. Large regional ponds may have water depths greater than 1.5 m.

Infants, small children and frail/elderly persons are considered unsafe in any flow without adult support. In cases where they are expected to be present without supervision, careful siting, design and fencing should be used to manage the risk appropriately.

Other adverse conditions that can affect the level of risk and should be taken into account are:

- bottom conditions – uneven, slippery, obstacles
- flow conditions – low temperature, poor visibility, unsteady flow and flow aeration which affects visibility of the bottom
- strong wind
- poor lighting.

If any of these adverse conditions are present and cannot be designed out, then lower water depths and velocities should be considered.

Life-saving equipment

Life rings and other pieces of public rescue equipment (PRE) have often been provided unnecessarily in the past. Thought should be given to the type of PRE needed (eg life ring or throw bags), if the water conditions and location suggest that one is needed (should anyone enter the water). For PRE to be effective, the person in the water needs to be noticed when in trouble, which is affected by the siting of a pond.

PRE is frequently abused and its presence can provide a false sense of security for those thinking of entering the water. Where they are provided, they should be regularly inspected, maintained and immediately replaced if used or missing.

Signs

In a public area, signs may be the only way of educating users about health and safety risks or how to use the rainwater runoff play system or feature. This can support local water safety or safety awareness activities, such as school based or community water safety training.

Signs may be used to educate the public. If deep water or other significant hazards exist (which are not recommended for SuDS design), the logical place for the display of safety signs is at all access points to sites, where all visitors will view the information. Therefore signs should be put in places such as entrances and visitors' car parks.

The following information should be included on the board (if appropriate):

- site name

- emergency instruction: “Dial 999 in an emergency”
- main hazard and prohibition symbols and supplementary text
- details of site supervision services and contact details
- location and postcode (needs to be understood by local emergency services)
- site map showing, rescue equipment, first aid and supervisory help, telephones
- organisational logos.

Signs and information are commonly provided with any PRE that is provided to form a “safety point” or “safety station”.

As well as the information provided at access points, provision should be made to repeat the message along routes adjacent to the water’s edge, where specific higher risk situations exist. These are known as “nag signs”, and are repeat messages, small reinforcement messages of key hazard or prohibition messages given previously on the primary or secondary signs. They should relate directly to the hazard that they are in close proximity to and should be predominantly symbol-based messages with reinforcing text. They are normally located next to the hazard, at places where visitors are most likely to access the water. These could be (for example):

- pinch points on walkways or paths
- jetties or platforms
- locations where entry might be expected
- viewing platforms
- other key hazards determined on site.

There will be many locations on site where nag signs can be placed. However, it is crucial, that only the key locations are signed; using too many nag signs will have a detrimental effect on the overall message.

Where the system includes significant areas of open water, the site will require monitoring for ice formation, and appropriate temporary warning signs will be needed (RoSPA should be approached for advice in such scenarios).

36.3.3 Slip and fall risk management

Physical injuries, such as falls, slips, trips and entrapment, should be no more prevalent at SuDS components than at any other natural or amenity feature, provided that good design principles have been followed and that consideration has been given to the potentially increased likelihood of wet and slippery conditions.

Of the 407 reported cases of drowning in 2011 (NWSF, 2012), 87 resulted from walking or running next to water. The steepness of the bank, freeboard, condition of the pathways and additional hazards should all be given significant consideration to ensure that a trip or stumble does not result in a fall into deep or fast flowing water. This includes consideration of the perception and abilities of the very young, very old and people with disabilities, as much as lighting and the expected site activities.

Accessible surfaces that convey runoff, or through which runoff is designed to pass, may be more vulnerable to a deterioration in structural integrity or build-up of algae that can cause the surface to become slippery, and potentially result in ice formation during winter months.

Structural integrity

All SuDS components should be structurally sound for use, taking into account the likelihood of vandalism or misuse, the durability of materials and the planned maintenance regime.

Any structural surfaces designed for accessibility should be suitably slip resistant, particularly those where surface water flow can be expected. The risks associated with ice formation should also be considered and managed appropriately, but the same considerations as for general water safety will apply – shallow water features are preferred.

Vertical drops and steep-sided structures

Good SuDS design should avoid the need for high vertical drops or deep steep-sided structures. In many cases, such hazards can be avoided by sensible profiling slopes of headwalls, or risks reduced by locating such structures away from open water. High headwalls should not be necessary in an efficient drainage design where flows are managed in sub-catchments.

If steep slopes and high vertical drops cannot be removed from the design, consideration should be given to how the risk is managed effectively and to access arrangements for maintenance (this is a CDM requirement). Vehicle movements should also be given careful consideration where SuDS are close to roadways.

Level changes

Unexpected changes in level, particularly if not immediately visible, should be avoided. Slopes should be gentle, at 1 in 3 or less, where accessible, and other changes in level visible and expected.

Inlets, outlets and safety grilles

Safety grilles are only required on pipes of ≥350 mm diameter (WRc, 2012). An efficient SuDS design should not require large pipes in most cases. Where grilles are provided, they should follow the guidance in WRc (2012).

36.3.4 Ill health from untreated or polluted water risk management

Rainwater runoff in SuDS components is no different from the water that runs across roads and car parks and stands as puddles for lengthy periods after rainfall. Many existing water features in parks and public open spaces already take highway runoff. Indeed, with good SuDS design and effective source control, accessible SuDS components should contain “treated” runoff, and therefore any pollution levels should be very low.

However, as with any natural water bodies, water in SuDS could potentially contain toxins that could potentially cause ill health, and there are management principles that should be followed to minimise potential risks.

Blue-green algae, leptospirosis, cryptosporidium and E. coli are examples of possible toxins. However, as with pollutants, the risks associated with the presence of these in SuDS components should be, at worst, no greater than in, for example, recreational ponds in parks, and it should be lower in a well-designed SuDS Management Train that removes pollution at source. Robust routine inspection and operation and maintenance practices should deal with the low risks associated with these hazards.

Weil’s disease and blue-green algae

Weil’s disease is a form of bacterial infection also known as leptospirosis which is carried by animals, most commonly in rats and cattle. It can be caught by humans through contact with rat or cattle urine, present in contaminated fresh water, including ponds, lakes, rivers and canals. Infection of humans usually occurs where open wounds are immersed in contaminated water.

Employees who work near water should be provided with a workers’ card that can be presented to their doctor if symptoms appear. This means that they can be diagnosed and treated quickly, reducing the likelihood of severe infection.

Blue-green algae tends to occur in warm water bodies with high nutrient content. “Stagnant” water is polluted water with a high nutrient content.

Water in SuDS should not be stagnant, but have low nutrient levels and be relatively clean. Nutrient removal upstream of pond systems should be considered in the design.

Disease-carrying and/or nuisance insects

There are a number of nuisance insects that use temporary water to lay eggs with the characteristic comma-shaped larvae changing into adults in 2–3 weeks in summer. Mosquitos are one of these insects, but the high-risk diseases that they are known to carry (eg malaria, West Nile virus) are not found in the UK, and mosquitos here are not currently implicated in the transmission of any diseases. Mosquitos are a natural part of the ecosystem, and many species such as bats, birds, invertebrates and amphibians, plus dragon fly nymphs predate on them. The most likely habitat for mosquitoes will be features such as water butts, which should therefore be covered at all times, blocked roof drainage gullies or other small stagnant water-containing features occurring in or around gardens.

There are measures that can reduce the nuisance of breeding insects. Their larvae are often predated by other living things within a balanced pond habitat and this should be the objective of any permanent or temporary water body design.

Gastro-intestinal disorders resulting from touching (and subsequent accidental ingestion) of roof-harvested rainwater

Theoretically, such disorders could result from children playing with rainwater harvested from roofs, where the roof is contaminated by bird and/or animal faeces. However, a literature review of potential health risks from roof harvested rainwater suggests that the hazard is likely to be very low.

In summary:

- faecal contamination indicators for roof runoff have been found to be insignificant or very low
- faecal coliform counts from roofs have been found to be significantly lower than for streets and driveways
- the risk associated with the use of harvested runoff for showering and/or hosing gardens has been gauged to be well below acceptable levels (and therefore even lower for SuDS where the pathogens are not aerosolised)
- the health risk associated with direct ingestion of a harvested supply due to cross-connections associated with a rainwater harvesting system has been gauged to be lower than the risk of being struck by lightning.

Safe working practices

The risk of contaminated, stagnant water occurring in well-designed SuDS components/schemes is very low, and the subsequent risk of a resultant adverse health issue is even lower. Those most likely to be at risk will be maintenance staff, and safe systems of work should be observed to mitigate any remaining risk. Checking for open cuts, and the use of nitrile gloves, waterproof plasters or other skin coverings should be considered wherever working in or near any open water body, including SuDS.

For maintenance operatives, employers have a duty to employees to inform them about the risks of their work environment and to decrease the risk as far as is reasonably practicable. This includes personal protective equipment (PPE) provision and policy implementation based on risk assessment. Employees who work near water should be provided with a workers’ card that can be presented to their doctor if symptoms that relate to water body exposure appear. This means that they can be diagnosed and treated quickly, reducing the likelihood of severity of infection.

Litter management

A robust litter management strategy should be implemented for all sites, as part of good landscape maintenance practice, through the provision of litter bins and regular litter collection and site litter picks. This will reduce the risks of rats frequenting the area looking for food. The importance of litter removal and the potential risks associated with waterborne diseases should be addressed as part of public education material.

Water quality management

Where water bodies are accessible amenity features, the upstream SuDS Management Train should have removed the majority of contaminants, delivering a relatively clean flow of freshwater to the pond or wetland component.

Where rainwater is captured in amenity play features, this water is likely to contain contaminants, and therefore drinking by children should be actively discouraged. However, roof water is relatively clean, and contact should not normally be a problem, although it is recommended that measures are taken to discourage the use of large roofs by large colonies of flocking birds or rodents where the runoff is to be harvested for use. If the design of the SuDS uses the conveyance or storage of rainwater to provide further intermittent play opportunities for slightly longer periods of time after it has rained, the water should be treated at least once, if it is not roof water, using SuDS treatment measures such as gravel filters or vegetation filters. If runoff is captured from busy roads, it should go through at least two cleaning stages before it is suitable for play.

Rainwater harvesting system design

RWHs should be designed to BS 8515:2009+A1:2003 so that the collection and storage facility is fit for purpose and includes all appropriate features to guard against undue risk. Any mains water supply that may be installed for example to ensure continuity of supply in dry spells, must be configured with backflow protection in accordance with the Water Supply (Water Fittings) Regulations 1999. The stored water is certain to contain some foreign material from the catchment surfaces and this could include guano, plant and animal remains, and legionella has also been identified in harvested rainwater. It is therefore a requirement of the Control of Substances Hazardous to Health Regulations 2002 to carry out a suitable and sufficient assessment of the risks constituted by any potentially pathogenic microbes in the context of the installation, its mode of operation and the proposed use of the water.

36.3.5 Aircraft safety risk management

Arrangements for airport safeguarding are explained in ODPM (2003), which includes the text of the Town and Country Planning (Safeguarded Aerodromes, Technical Sites and Military Explosives Storage Areas) Direction 2002. Consultation is required within a 13 km zone around an aerodrome where a proposed development is likely to attract birds. Note that the term “aerodrome” is defined in the Civil Aviation Act 1982 and is essentially an area of land or water set aside for aircraft to land or take off. Airport is defined in the Airports Act 1986, and is the aerodrome plus all the buildings and facilities.

Generally, decisions concerning local land use and planning issues, including cases where local aerodromes may be affected, are the responsibility of the local planning authorities. The Civil Aviation Authority (CAA) is not routinely a statutory consultee for planning applications. The CAA does have a role in providing relevant aviation safety advice upon request.

In all cases, aerodrome safeguarding responsibility rests with the aerodrome licence holder/operator (not the CAA). Therefore, any local planning authority enquiry concerning a specific development that might have aerodrome safeguarding implications should be forwarded directly to the relevant aerodrome licence holder/operator.

The CAA has identified SuDS components, in particular ponds, wetlands and green roofs, as a potential hazard to aircraft. Although the main concern is wildfowl including flocks of ducks, geese and swans, there is also concern about other flocking species such as rooks, starlings and gulls. Further advice is provided in AOA and GAAC (2006).

The risk to aircraft can be mitigated by good ecological design including:

- long grass rather than the short grass preferred by geese
- small pools and ponds with edges accessible by predators such as foxes
- planting design to reduce the risk of roosting by birds in large numbers.

The use of certain SuDS components near to aerodromes will also depend on the site-specific circumstances such as location relative to the aerodrome and location of other features in the area that are attractive to birds.

This is a complex subject, and specialists in bird strike prevention and safeguarding aerodromes should be consulted. Smaller open SuDS components, such as small swales and small shallow ponds, and associated features, such as rills and small canals or channels, are not likely to attract birds any more than a garden pond or lawn.

36.4 HEALTH AND SAFETY RISK ASSESSMENT REQUIREMENTS

36.4.1 Background

Good SuDS design and risk management processes during design (following the guidance and principles set out earlier in this chapter) should deliver drainage systems that are safe. The requirements of the CDM hierarchy should be adopted: identify, eliminate, reduce, control.

There will, however, remain a need for designers of drainage systems to check (and also demonstrate and record) that health and safety risks have been considered and suitably mitigated by the design. Those bodies approving and adopting SuDS will also require a health and safety check so that the long-term safety of the local community, those visiting the site and operation and maintenance operatives are not compromised. Such records are essential to minimise the risk of being held liable for any future health and safety incident that occurred on a site.

The following section sets out a proposed approach to consistent health and safety risk assessment for SuDS, in-line with the principles set out in BS EN 31010:2010. The guidance and principles set out in Section 6 should be referred to when assessing the level of risk for any particular item. Legislation relevant to health and safety risk management for SuDS is summarised in **Section 36.5**, for context and ease of reference.

36.4.2 Risk assessment

There is a need to be able to determine the following issues with respect to risk at any particular drainage site:

- Which site/system characteristics potentially represent hazards?
- When might these hazards represent a “risk” (either independently or together)?
- To what extent might the local/visiting population be vulnerable to the hazard?
- What is the likelihood of a “consequence” occurring?
- At what level is the risk, and how acceptable is it, taking the local cultural context into account?
- Would mitigation of the risk reduce the societal benefit derived from the SuDS?
- Are the risks small enough to be acceptable?

Risk assessment involves systematically identifying hazards (ie anything that has the potential to cause harm), the evaluation of the risks related to those hazards and the establishment of control measures in order to reduce the risk to as low as is necessary or appropriate.

Risk–benefit assessment starts with (a) identifying the benefits (eg visual amenity, recreational, biodiversity or use of pond for educational purposes), (b) considering the potential risks; (c) reviewing the possible responses to these risks before making a judgement on measures. All elements should be fully recorded in order to provide an audit trail (Gill, 2010).

The following process (and the checklist provided in **Appendix B**) is based on principles that are widely used in other risk assessment fields, including CDM risk assessments.

A risk assessment process is shown in **Figure 36.1**.

A risk assessment should be carried out as part of the design of SuDS. It should be evaluated by the drainage approving body, revisited at construction inspection and adoption approval stages and monitored and reviewed as part of the site maintenance procedures.

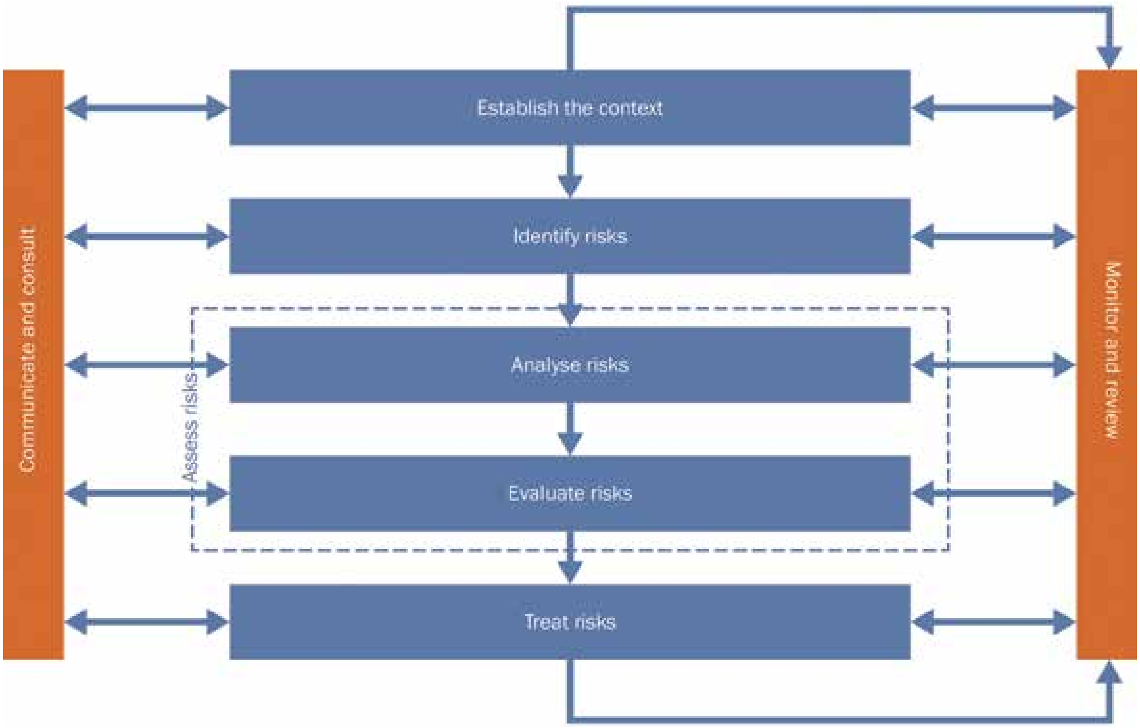

Figure 36.1 Risk assessment process

Risk is a combination of the likelihood of something occurring and the consequences if it does occur. A common method of assessing risk in many other fields is to use a risk matrix such as the one provided in **Table 36.2**. The greater the consequences the lower the probability of occurrence has to be for the risk to be acceptable. For example, drowning to children is a rare but socially unacceptable event.

TABLE 36.2 SuDS risk assessment matrix

		Consequence				
		Insignificant	**Minor**	**Moderate**	**Major**	**Extreme**
Likelihood		**No injury or health effects**	**Minor injury or health effects**	**Injury but not life threatening Some ill health effects**	**Serious injury Dangerous near miss Serious ill health**	**Serious injury or death Serious life-threatening disease**
Almost certain (frequent)	Is expected to occur/ recur frequently or within a short period of time (most weeks or months)	M	M	H	E	E
Likely (probable)	Will probably occur/ recur in most circumstances (several times a year)	L	M	H	H	E
Possible (occasional)	Possibly will occur/ recur occasionally (once every few years)	L	M	M	H	H
Unlikely (uncommon)	Uncommon might occur/recur at some time in the future	L	L	M	M	H
Rare (remote)	Unlikely to occur/ recur May only happen in exceptional circumstances	L	L	L	L	M

Key

Risk	**Action**
Extreme risk (E)	Design stage – not acceptable – design must be changed Management stage – immediate attention and response needed to reduce the level of risk
High risk (H)	Design stage – not acceptable – design must be changed Management stage – attention and response needed to reduce the level of risk
Medium risk (M)	Design stage – review if it is practical and reasonable to change design to reduce level of risk Management stage – review options to see if there are practical and reasonable options to reduce risk
Low risk (L)	Design stage – acceptable – no changes required Management stage – no response needed to reduce the level of risk, continue to review on regular basis

36.5 HEALTH AND SAFETY LEGISLATION

The UK health and safety laws are designed to ensure that those in control of premises do what is reasonably practicable to ensure the safety of employees, contractors and the public.

The following statutory instruments impose obligations and duties to ensure that staff and members of the public are not exposed to risks to their health and safety:

- The Health and Safety at Work etc Act 1974
- The Management of Health and Safety at Work Regulations 1999
- The Occupier's Liability Acts of 1957 and 1984
- The Public Health Act 1936.

Health and safety of structures, including SuDS, starts with design, and all SuDS designers must be familiar with and follow the specific requirements of CDM 2015. CDM 2015 is aimed at improving the overall management and co-ordination of health, safety and welfare throughout all stages of a construction project and the Regulations place duties on all those who can contribute to the health and safety of a structure. Risk assessments at the design stage are an important step and should include the identification of any hazards in the design, suitable actions to eliminate or reduce the risks to builders, maintainers and users of the structure (eg the public) and the information required regarding residual risks in order that they may be effectively controlled on site. Early design decisions and assumptions affect health and safety because they influence the choice of materials, construction methods and the build programme, as well as design characteristics and SuDS locations. In addition to the CDM Regulations, designers should consider the implications of the Building Regulations in terms of access and protection from falls and any additional requirements that may be relevant to meet the requirements of the Management of Health and Safety at Work Regulations 1999. The Workplace (Health, Safety and Welfare) Regulations 1992 will also apply as the SuDS scheme will become a workplace from time to time during maintenance.

Consideration needs to be given to the whole SuDS scheme and not just any ponds that may be created. For example:

- Will roof maintenance be needed on a green roof. If so, how will this be conducted safely? For example, will harness eye bolts be needed?
- Will permeable paving become uneven quickly? How will this be inspected and managed?
- Will rills be used for paddling? How will this be encouraged safely?

The asset owner or occupier is ultimately responsible for conducting a suitable and sufficient assessment of the SuDS for the use, inspection and maintenance of the system. However, the owner will need sufficient information from the designer and developer to conduct this assessment and to be confident that the system meets the required standards prior to adoption.

Under common law, the SuDS owner or occupier has a duty to potential visitors "to take reasonable care to avoid acts or omissions which you can reasonably foresee would be likely to injure your neighbour". Reasonable care is defined as "what a reasonable person would have foreseen as being necessary" and acknowledges that a certain level of risk is acceptable and it is expected that appropriate safety measures will be applied in each circumstance. Each location and SuDS scheme will be different and therefore blanket designs, features and characteristics will not necessarily be effective or appropriate.

The Occupiers' Liability Acts (OLA) of 1957 and 1984 govern to what extent landowners are responsible for the health and safety of visitors and trespasses to their premises. Case law should be referenced to clarify the specific implications of each of the Acts for SuDS owners and operators.

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STATUTES

Acts

Airports Act 1986 (c.31)

Disability Discrimination Act 1995 (c.50)

The Control of Substances Hazardous to Health Regulations 2002 (No.2677)

Health and Safety at Work etc Act 1974 (c.37)

The Management of Health and Safety at Work Regulations 1999 (No.3242)

Occupier's Liability Act 1957 (c.31)

Occupier's Liability Act 1984 (c.3)

Public Health Act 1936 (c.49)

Water Supply (Water Fittings) Regulations 1999 (No.1148)

Workplace (Health, Safety and Welfare) Regulations 1992 (No.3004)

Regulations

Construction (Design and Management) (CDM) Regulations 2015

Standards

BS 8515:2009+A1:2003 *Rainwater harvesting systems. Code of Practice*

BS EN 31010:2010 *Risk management. Risk assessment techniques*

Everyone with an interest in SuDS

Those responsible for policy or decision-making

Those responsible for delivering and managing SuDS schemes

Part A : Introduction to the SuDS manual

A high-level introduction to the concept of SuDS, what they are and why we need them.

Part B : Philosophy and approach

The philosophy of SuDS and their role in managing water quantity and water quality, whilst maximising the benefits for amenity and biodiversity.

How to design SuDS to deliver these objectives by following design criteria and standards.

Part C : Applying the approach

The design process and how to apply the design criteria and standards presented in Part B to different types of development.

Part D : Technical detail

Detailed descriptions of different types of SuDS components, with guidance on design, construction, operation and maintenance.

Part E : Supporting guidance

Additional guidance to support the planning, design and implementation of SuDS.

Appendices

A

Audience:
Everyone with an interest in SuDS
Those responsible for policy or decision making
Those responsible for delivering and managing a SuDS scheme

Appendices

Image courtesy Peterborough City Council

Image courtesy Arup

APPENDIX A GLOSSARY AND ABBREVIATIONS

Contents

Appendix A Glossary and Abbreviations

GLOSSARY

Adopting/ adoption body	The organisation responsible for taking ownership of the SuDS.
Adaptability	The degree to which a system can be adapted to better suit changing circumstances or conditions (see *flexibility*).
Adsorption	The adherence of gas, vapour or dissolved matter to the surface of solids.
Amenity	The quality of being pleasant, attractive, desirable and/or useful.
Approving/ approval body	The organisation responsible for approving the SuDS.
Aquatic bench	A flat or almost flat surface around the inside perimeter of a permanent pond. Normally vegetated with emergent plants, the bench augments pollution removal, provides habitat and enhances safety.
Aquifer	A subsurface zone or formation of rock or soil containing a body of groundwater.
Asphalt	European standard description of all mixtures of mineral aggregates bound with bituminous materials used in the construction and maintenance of paved surfaces.
Attenuation	Reduction of peak flow rate and increased duration of a flow event.
Attenuation storage	Volume in which runoff is stored when the inflow to the storage is greater than the controlled outflow.
Baffle	A device designed to extend flow paths through a pond.
Base flow	The sustained flow in a channel or drainage system.
Basin	A ground depression that is normally dry, designed to store surface water before infiltration (see *infiltration basin*) and/or provide attenuation (see *detention basin*).
Benefit–cost ratio	The ratio between the benefits and costs of a scheme; used to determine whether it is value for money.
Benefit transfer	A method for transferring the values ascribed to a good, service or attribute from one survey or study in relevant ways to another decision or policy context, thereby avoiding the need to repeat the survey or study.
Bentonite	A colloidal clay, largely made up of the mineral sodium montmorillonite, a hydrated aluminium silicate.
Berm	A shelf or raised barrier separating two areas.
Binder course	European standard description of the second layer of an asphalt pavement currently known in the UK as basecourse.
Biochemical oxygen demand (BOD)	The measure of the concentration of biodegradable organic carbon compounds in solution. Used as a water quality indicator.

Biodegradable	Capable of being decomposed by bacteria or other living organisms.
Biodegradation	Decomposition of organic matter by microorganisms and other living things.
Biodiversity	The diversity of plant and animal life in the world, an area or a particular habitat – a high level of which is usually considered to be important or desirable.
Biofiltration	Filtration using living materials (see *filtration*).
Bioretention system	A shallow planted depression that allows runoff to pond temporarily on the surface, before filtering through vegetation and underlying soils prior to collection or infiltration. In its simplest form, it is often referred to as a rain garden. Engineered soils (gravel and sand layers) and enhanced vegetation can be used to improve treatment performance.
Bitumen	A hydrocarbon binder. A virtually non-volatile adhesive material derived from crude petroleum that is used to coat mineral aggregate for use in construction and maintenance of paved surfaces.
Block paving	Paving designed to allow rainwater falling onto the surface or runoff discharged over the surface to infiltrate through the joints or voids between the blocks into the underlying pavement structure (see *permeable pavements*).
Blue roof	A roof construction that stores water; can include open water surfaces, storage within or beneath a porous media or modular surface or below a raised decking surface or cover.
Blue space	Similar to green space, but it is an area of water rather than vegetation.
Breakthrough head	The water pressure required to cause a flow of water through the material (eg geotextile).
Brownfield site	A site that has been previously developed.
Brown roof	A roof that incorporates a substrate (laid over a waterproof membrane) that is non-planted and allowed to colonise naturally. Sometimes referred to as an alternative roof.
Buffer	Something that helps reduce the scale of an impact.
Bund	A barrier, dam or mound usually formed from earthworks material and used to contain or exclude water (or other liquids) in/from an area of the site.
California bearing ratio (CBR)	An empirical measure of the stiffness and strength of soils, used in road pavement design.
Capping layer	A layer of unbound aggregate of lower quality than sub-base, that is used to improve the performance of the foundation soils before laying the sub-base, and to protect the subgrade from damage by construction traffic.
Carriageway	That part of the road used to carry vehicular traffic.
Catchment	The area contributing surface water flow to a point on a drainage or river system. Can be divided into sub-catchments.
Catchpit	A small chamber incorporating a sediment collection sump that the runoff flows through.
Chemical oxygen demand (COD)	The measure of the amount of oxygen taken up by chemical oxidation of a substance in solution. Used as a water quality indicator.
Climate change	A change in the state of the climate that can be identified (eg by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes, to external forcings or to persistent anthropogenic changes in the composition of the atmosphere, ocean or in land use.
Climate change scenarios	A coherent, internally consistent and plausible description of possible future changes in climate, usually based on specific assumptions.
Climate resilience	The capacity of a system to cope with a hazardous climate event or trend or disturbance, responding or reorganising in ways that maintain (or recover) its essential function, identity and structure, while also maintaining the capacity for adaptation (see *adaptability*).

Coliform	Bacteria found in the intestines, faeces, nutrient rich waters, soil and decaying plant matter.
Combined sewer	An underground pipe designed to carry both foul sewage and surface water runoff.
Combined sewer overflow (CSO)	A structure on a combined or partially separate sewer system that allows the discharge of flow in excess of that which the sewer is designed to carry, usually to a receiving surface water body.
Construction quality assurance (CQA)	A documented management system designed to provide adequate confidence that items or services meet contractual requirements and will perform adequately in service. CQA usually includes inspection and testing of installed components and recording the results.
Contaminated ground	Ground that has the presence of substances that, when present in sufficient quantities or concentrations, could cause significant harm to people or protected species or significant pollution of surface waters or groundwater.
Contingent valuation	A method, using sample evidence from questionnaires and surveys, that estimates how much people would be willing to pay for specific environmental or social benefits.
Continuously graded	A soil or aggregate with a balanced range of particle sizes with significant proportions of all fractions from the maximum nominal size down.
Control structure	A structure to control the volume or rate of flow of water through or over it.
Conventional drainage	The method of draining surface water using subsurface pipes and storage tanks.
Conveyance	Movement of water from one location to another.
Cost-effective	Something that is value for money. In economic terms, the benefits received and/or services delivered are worth at least what is paid for them.
Cost-effectiveness analysis (CEA)	A form of economic analysis that compares the relative cost to benefit, sometimes described as the change in outcome for a unit of investment.
Costs avoided	Future costs that will not appear as a result of an action, where it is reasonably certain that the cost would have appeared otherwise.
Creep	A load placed on a polymer material will result in an initial deformation, but with the load remaining over time, further deformation will continue to occur. The rate of creep becomes greater as the applied load increases.
Critical duration event	The duration of rainfall event likely to cause the highest peak flows or levels at a particular location, for a specified return period event.
Cross-contamination	Pipes carrying mains water connected to pipes carrying non-potable water.
Curtilage	Land area within property boundaries.
Degradation	Being broken down to a less complex/lower state.
Denitrification	A microbial process that reduces nitrate to nitrite and then nitrite to nitrogen gas.
Deposition	Laying down of matter via a natural process.
Designated drainage system	All parts of a drainage system (including above-ground conveyance and storage areas that may only be used relatively infrequently) that form the management of surface water runoff up to the designed level of service.
Design criteria	A set of agreed criteria that the proposed system should be designed to satisfy.
Design event	A synthetic rainfall event of a given duration and return period that has been derived by statistical analysis.
Designing for exceedance	See *exceedance design.*
Detention	The temporary storage of water to attenuate flows.
Detention basin	A landscaped depression that is normally dry except during and following rainfall events. Constructed to store water temporarily, to attenuate flows and, where vegetated, provide treatment.

Development	Any area of land that has been or is being developed (ie land use change that includes construction). This includes new developments, redevelopments, infill and retrofit.
Development plan	Sets out the policies and proposals for the development, conservation and use of land and buildings in a particular local planning authority (LPA) area. It is the most important consideration for LPAs when they decide on a planning application. The plan generally includes development plan documents that are part of a LPAs local plan.
De-watering	The lowering of groundwater/surface water levels or the removal of water from a substance.
Diffuse pollution	Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment, or sub-catchment, and do not arise as a process effluent, municipal sewage effluent or an effluent discharge from farm buildings.
Discharge consent	Permission to discharge effluent, subject to conditions laid down in the consent, issued by the relevant environment regulator.
Discounting	A method to compare the benefits and costs that arise over the appraisal period. The discount rate converts all costs and benefits to the present day to determine the present value (PV) or whole life cost (WLC) so that they can be evaluated consistently.
Dissolved oxygen (DO)	The amount of oxygen dissolved in water. Oxygen is vital for aquatic life, so this measurement is a test of the health of a river. Used as a water quality indicator.
Double counting	Where costs are included more than once in a valuation exercise.
Duty of care	To take reasonable care to avoid acts or omissions which you can reasonably foresee would be likely to injure your neighbour.
Ecology	The study of plants (flora) and animals (fauna) and the relationships between them and their physical environment.
Ecosystem	A biological community and its physical environment.
Ecosystem services	The benefits provided by ecosystems that contribute to making human life both possible and worth living. Examples of ecosystem services include products such as food and water, regulation of floods, soil erosion and disease outbreaks, and non-material benefits such as recreational and spiritual benefits in natural areas.
Environmental regulator	The primary environmental regulators in the UK are: the Environment Agency in England, Natural Resources Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency. Other organisations that have regulatory responsibilities relating to the environment include local authorities (with respect to, for example, contaminated land and tree preservation), Natural England and Scottish Natural Heritage (with respect to nature conservation).
Erosion	The group of natural processes, including weathering, dissolution, abrasion, corrosion and transportation, by which material is worn away from the earth's surface
Estuary	A semi-enclosed body of water in which seawater is substantially diluted with freshwater entering from land drainage.
Eutrophication	Water pollution caused by excessive plant nutrients that results in reduced oxygen levels. The nutrients are powerful stimulants to algal growth which in turn use up oxygen in water. The excessive growth, or "blooms", of algae promoted by these phosphates change the water quality in lakes and ponds which can kill fish.
Evapotranspiration	The process by which the Earth's surface or soil loses moisture by evaporation of water and by uptake and then transpiration from plants.
Exceedance design	Designing a system to manage effectively events that exceed (ie are bigger and rarer than) the drainage system's required level of service.
Exceedance event	A rainfall or flow event that exceeds (ie is bigger and rarer than) the design event, not to be confused with an extreme event.
Extreme event	A rainfall or flow event that is relatively rare, generally considered to be an event with a return period of 30 years or more, not to be confused with an exceedance event.

Fatigue	Fatigue is loss of strength that occurs due to repeated application of traffic or other loads which may reduce the strength of the units in the long term.
Filter drain	A linear drain consisting of a trench filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage.
Filter strip	A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and to filter out silt and other particulates.
Filtration	The act of removing sediment or other contaminants from a fluid by passing it through a filter.
Fines	Small soil particles less than 63 microns in size.
First flush	The initial runoff from a site or catchment following the start of a rainfall event. As runoff travels over a catchment it will collect or dissolve pollutants, and the "first flush" portion of the flow may be the most contaminated as a result. This is especially the case for intense storms and in small or more uniform catchments. In larger or more complex catchments pollution wash-off may contaminate runoff throughout a rainfall event.
Flexibility	The ability to cope with a range of conditions or requirements.
Flood Consequence Assessment (FCA)	The Welsh Government's requirement for assessing the potential consequence of flooding on a development or caused by the development, as set out in TAN 15. Similar to a *Flood Risk Assessment (FRA)*.
Flood frequency	The concept of the probable frequency of occurrence of a flood event of a given size.
Floodplain	The area that would naturally be affected by flooding (ie in the absence of flood defences or certain other manmade structures and channel improvements) if a river rises above its banks or high tides and stormy seas cause flooding in coastal areas.
Flood Risk Assessment (FRA)	An assessment of the risk of flooding on a development or caused by the development required as part of the planning application process in England, Scotland and Northern Ireland (see *Flood Consequence Assessment* for Welsh equivalent).
Flood risk management	Holistic and continuous analysis, assessment and reduction of flood risk.
Flood routing	Design and consideration of above-ground areas that act as pathways permitting water to run safely overland to minimise the adverse effect of flooding. This is required when the design capacity of the drainage system has been exceeded.
Flow control device	A device used to limit the flow through the outlet from a SuDS component, usually necessary to meet a required discharge rate.
Forebay	A small basin or pond upstream (or at the upstream end) of the main drainage component, with the function of trapping sediment.
Formation level	Surface of an excavation prepared to support a pavement or other overlying structure.
Foul drainage	The infrastructure that drains the water and sewage that is discharged from within houses.
Foul sewer	An underground pipe designed to carry only foul sewage.
Freeboard	Distance between the design water level and the top of a structure, provided as a precautionary safety measure against early system failure.
Frequent (rainfall) event	Rainfall events that happen more often than once a year.
Geocellular storage systems	Modular plastic units with a high porosity (generally around 95%) that can be used to create a below-ground structure for the temporary storage of surface water before controlled release or use. The storage structure (tank) is formed by assembling the required number of individual units (sometimes in several layers) and wrapping them in either a geotextile or a geomembrane.
Geocomposite	A form of geosynthetic that is made by creating a single component from two or more elements (eg a drainage core and a geotextile).
Geogrid	Plastic grid structure used to increase the strength of soils or aggregates.

Geomembrane	An impermeable plastic sheet, typically manufactured from polypropylene, high density polyethylene or other geosynthetic material.
Geosynthetics	Manmade products used to stabilise groundworks. These include geotextiles, geomembranes, geocomposite clay liners and geocomposite drainage products.
Geotextile	A permeable fabric that can separate, filter, reinforce, protect or drain.
Green corridor	A strip of land in an urban area that can support habitats and allows wildlife to move along it. Typically includes cuttings, embankments, roadside grass verges, rights of way, rivers and canal banks.
Greenfield	Relating to land that has never been developed, other than for agricultural or recreational use.
Greenfield runoff	The surface water runoff regime from a site before development.
Green infrastructure	A strategically planned and delivered network of natural and manmade green (land) and blue (water) spaces that sustain natural processes. It is designed and managed as a multi-functional resource capable of delivering a wide range of environmental and quality of life benefits for society.
Green roof	A roof with plants growing on its surface, which contributes to local biodiversity. The vegetated surface provides a degree of retention, attenuation and treatment of rainwater, and promotes evapotranspiration.
Green space	An area of grass, trees or other vegetation set apart for recreational or aesthetic purposes in an otherwise urban environment.
Gross solids	Large solids, usually organic in nature, either floating, suspended or deposited, which have a polluting effect on the receiving water.
Groundwater	Water that is below the surface of the ground in the saturation zone.
Groundwater protection zone	See *source protection zone*.
Gully/gulley	Opening in the road pavement, usually covered by metal grates, which allows water to enter conventional drainage systems.
Gulley erosion	The erosion of soils by surface runoff, resulting typically in steep-side channels and small ravines, poorly consolidated superficial material or bedrock by streams or runoff water.
Habitat	The area or environment where an organism or ecological community normally lives or occurs.
Hazard	A property, situation or substance with potential to cause harm.
Heat island effect	See *urban heat island effect*.
Heave	The opposite of subsidence. The upward movement of the ground. See *subsidence*.
Heavy metal	Loosely, metals with a high atomic mass (sometimes given as metals with an atomic mass greater than that of calcium), often used in discussion of metal toxicity. No definitive list of heavy metals exists, but they generally include cadmium, zinc, mercury, chromium, lead, nickel, thallium and silver. Some metalloids, such as arsenic and antimony, are classified as heavy metals for discussions of toxicity.
Hedonic pricing	A method used in benefit valuations that relies on indirect information that gives an indication of willingness to pay for benefits, such as that provided by households when they make their property purchase location decisions.
Highways England	The government agency responsible for strategic highways in England, that is, motorways and trunk roads (formerly the Highways Agency). In other parts of the UK, this role is fulfilled by Transport Scotland, Welsh Government and Transport Northern Ireland.
Highway authority	A local authority with responsibility for the maintenance and drainage of highways maintainable at public expense.

Highway drain	A component draining the highway on highway land that is maintainable at the public expense; vested in the highway authority.
Hydraulics	A term for fluid mechanics used in the context of water engineering, and is the study of flows. In the context of this manual, hydraulics covers the storage, conveyance and control of flows within the proposed drainage network.
Hydrogeology	The study of water below the ground surface and geological aspects of surface water. In the context of this manual, it covers the dissipation of the rainfall-runoff beneath a permeable soil surface.
Hydrograph	A graph illustrating changes in the rate of flow from a catchment with time.
Hydrology	The study of the waters of the Earth, their occurrence, circulation and distribution; their chemical and physical properties; and their relation with the environment, including their relation to living things.
Hydrolysis	The chemical breakdown of a compound due to reaction with water.
Hyetograph	Temporal rainfall profile.
Impermeable	Will not allow water to pass through it.
Impermeable area	The area within a defined catchment that is impermeable, usually given as a percentage.
Impermeable surface	An artificial non-porous surface that generates a surface water runoff after rainfall.
Indicator	A means of measuring, at least in part, the extent to which design criteria are achieved.
Infiltration (to a sewer)	The entry of groundwater to a sewer.
Infiltration (to the ground)	The passage of surface water into the ground.
Infiltration basin	A dry basin designed to promote infiltration of surface water to the ground.
Infiltration component	A component specifically designed to aid infiltration of surface water into the ground.
Infiltration trench	A trench, usually filled with permeable granular material, designed to promote infiltration of surface water to the ground.
Initial rainfall loss	The amount of rain that falls on a surface before water begins to flow off the surface.
Inlet	A structure or landscape feature that manages the flow into a SuDS component.
Interception	The prevention of runoff from the site for the majority of small (frequent) rainfall events (or for the initial depth of rainfall for larger events).
Interception storage	The capture and/or storage of small rainfall depths before infiltration, evapotranspiration or use.
Interflow	Shallow movement of water through upper soil layers, from where it may infiltrate vertically to an aquifer, move horizontally to a watercourse or be stored and subsequently evapotranspired.
Joint probability	The calculated probability of two or more specific events occurring together.
Landscape	A term that encompasses the entirety of all external space, whether urban or rural, often considered in terms of their aesthetic appeal.
Land use	The main activity that takes place on an area of land based on economic, geographic or demographic use, such as residential, industrial, agricultural or commercial.
Lateral drain	That part of a drain that runs from the curtilage of a building (or buildings or yards within the same curtilage) to the sewer with which the drain communicates or is to communicate; or (if different and the context so requires) the part of a drain identified in a declaration of vesting made under section 102 or in an agreement made under Section 104 of the Water Industry Act 1991.
Leaching	The process during which soluble minerals may be removed from the soil by water percolating through it.

Lead local flood authority	Unitary authorities or county councils responsible for developing, maintaining and applying a strategy for local flood risk management in their areas and for maintaining a register of flood risk assets. Also responsible for managing the risk of flooding from surface water, groundwater and ordinary watercourses.
Leakage	The flow of water from one hydrologic unit to another. The leakage may be natural (as through a semi-impervious confining layer) or manmade (as through an uncased well).
Legibility	The degree to which a system can be readily understood by the public.
Legionella	A bacterium named *Legionella pneumophila* that can cause legionnaires' disease (lung infection) in humans.
Level of service	The performance of a system, either designed or measured. Also referred to as Standard of service.
List I substance	A controlled substance as defined under the Groundwater Regulations 1998 and Directive 76/464/EEC (Dangerous Substances Directive). List I substances are considered the most dangerous in terms of toxicity, bioaccumulation and persistence. These controls prevent their discharge to the environment.
List II substance	A controlled substance as defined under the Groundwater Regulations 1998 and the Directive 76/464/EEC (Dangerous Substances Directive). They are less toxic than List I substances but are still capable of harm, hence their discharge to the environment is limited.
Liveability	The degree to which a scheme enhances a community's quality of life, health and wellbeing, such as providing a link between the built and natural environments; providing educational, cultural, entertainment and recreational potential; and helping to support economic prosperity, social stability and equity.
Local flood risk management strategy	A local strategy for flood and coastal erosion risk management developed by the lead local flood authority, which acts as the evidence base for decisions and actions required to manage flood risk.
Local planning authority (LPA)	The local authority or council that is empowered by law to exercise town planning functions for a particular area of the UK. In Scotland, where all of the local authorities are unitary, the term "planning authority" is used without the "local" prefix.
Long-Term Storage Volume	The difference in runoff volume between the developed site and its greenfield (or previously developed) state. This is the volume that should be prevented from leaving the site (via rainwater harvesting and/or infiltration) or, where this is not possible, controlled so that it discharges at very low rates that will have negligible impact on downstream flood risk.
Macrophyte	Plants easily visible to the naked eye.
Maintainability	The ease with which a scheme can be safely and effectively maintained.
Management Train	The sequence of drainage components that collect, convey, store and treat runoff as it drains through the site.
Master plan	An overarching planning document and spatial layout that is used to structure future land use and development.
Mean annual flood (Q_{BAR})	The mean of the series of peak annual flow rates observed or estimated for a river at a particular location. Statistically, rivers and streams will equal or exceed the mean annual flood once every 2.33 years.
Micropool	Pool at the outlet from a pond or wetland that is permanently wet and improves the pollutant removal of the system.
Misconnection	An incorrect connection of an inlet or drain to a drain or sewer that is not designed to carry that element of flow (eg foul sewage entering a surface water system or surface water entering a separate foul system).
Model agreement	A legal document that can be completed to form the basis of an agreement between two or more parties regarding the maintenance and operation of sustainable water management systems.

Modular storage systems	A storage system designed as a series of standardised units that can be linked together to increase capacity.
Morphology	The characteristics, configuration and evolution of a river.
Multi-criteria analysis (MCA)	An umbrella term used for applying non-quantitative assessment techniques (alongside quantitative results where available), where stakeholders believe there are significant benefits beyond those that can be monetised that should be included in the decision-making process.
Multi-functional	Something that has or fulfils more than one function.
Multi-functionality	The degree to which a system can have or perform multiple functions.
Natural capital	The elements of nature that produce value to people, such as the stock of forests, water, land, minerals and oceans. These provide many benefits, by providing food, clean air, wildlife, energy, wood, recreation and protection from hazards.
Nature conservation bodies	The four organisations that have regional responsibility for promoting the conservation of wildlife and natural features: Natural England, Natural Resources Wales, Scottish Natural Heritage and Northern Ireland Environment Agency.
Net present value (NPV)	The difference between the present value of benefits and the present value of costs (see *present value*).
Non-potable water	Water not suitable for drinking.
Non-return valve	A pipe-fitting that limits flow to one direction only.
Nutrient	A substance providing nourishment for living organisms (such as nitrogen and phosphorus).
Off-line	A part of the drainage system that does not receive flows during frequent events.
Oil separator	A component designed to separate gross amounts of oil and sediments from surface water runoff.
On-line	A part of the drainage system that receives flows during all frequent events.
Organic pollution	A general term describing the type of pollution that, through the action of bacteria, consumes the dissolved oxygen in rivers. The effects of organic pollution are described by the levels of biochemical oxygen demand, ammonia and dissolved oxygen found in a water body.
Orifice plate	Structure with a fixed aperture to control the flow of water.
Outfall	The point, location or structure where surface water runoff discharges from a drainage system.
Outlet	A structure or landscape feature that manages the flow out of a SuDS component.
Overflow	The flow of water from a conveyance or storage component once the capacity of that component is exceeded. Not to be confused with a *combined sewer overflow*.
Oxidation	The combination of a compound with oxygen.
Pathogen	An organism that causes disease.
Pathway	The route by which potential contaminants may reach targets.
Pavement	The road or car park surface and underlying structure, usually asphalt, concrete or block paving. Note that the path next to the road for pedestrians (the UK colloquial term of pavement) is the footway.
Peak flow	The point at which the flow of water from a given event is at its highest.
Penstock	A sliding plate that moves vertically to vary the size of an aperture (or close it completely).
Percentage runoff	The percentage of the rainfall volume falling on a specified area that then runs off that surface.
Percolation	The passing of water (or other liquid) through a porous substance or small holes (eg soil or geotextile fabric).

Permeability A measure of the ease with which a fluid can flow through a porous medium. It depends on the physical properties of the medium, for example grain size, porosity and pore shape.

Permeable pavement A surface that is formed of material that is itself impervious to water, but is laid to provide void space through the surface to the sub-base.

Pervious area Area of ground that allows infiltration of water, although some surface runoff may still occur.

Pervious pavement A surface that provides a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater to infiltrate through the surface and into the underlying structural layers.

Pervious surface A surface that allows inflow of rainwater into the underlying construction or soil.

Photolysis The breakdown of surface-held organic pollutants by exposure to ultraviolet light.

Phytoremediation The treatment of pollutants in soils, water or air through the use of plants.

Place-making A multi-faceted approach to the planning, design and management of public spaces with the intention of creating public spaces that promote people's health and wellbeing.

Point source pollution Pollution that arises from an easily identifiable source, usually an effluent discharge pipe.

Pollution A change in the physical, chemical, radiological or biological quality of a resource (air, water or land) caused by man or man's activities that is injurious to existing, intended or potential uses of the resource.

Pollution prevention strategies Site design and management to stop or reduce the occurrence of pollution of surface water runoff.

Pond Permanently wet depression designed to temporarily store surface water runoff above the permanent pool and permit settlement of suspended solids and biological removal of pollutants.

Porosity The percentage of the bulk volume of a rock or soil that is occupied by voids, whether isolated or connected.

Porous asphalt An asphalt material used to make pavement layers pervious, with open voids to allow water to pass through (previously known as pervious macadam).

Porous pavement A permeable surface that allows water to infiltrate across the entire surface material through voids that are integral to the pavement.

Porous surface A surface that infiltrates water to the sub-base across the entire surface of the material forming the surface, for example grass and gravel surfaces, porous concrete and porous asphalt.

Potable water Water suitable for drinking.

Precipitation

1. (meteorology) Any product of the condensation of atmospheric water vapour that falls under gravity, including rain, sleet, snow and hail.
2. (chemistry) A chemical reaction between pollutants and compounds in the soil or aggregate matrix that transforms dissolved constituents into insoluble particles.

Pre-treatment The removal of contaminants (usually sediments) that may reduce the treatment performance of a specific downstream component.

Present value (PV) The value in the present, of a sum of money; in contrast to some future value it will have when it has been invested and accrued compound interest. If a cost is assumed to be required at some future date, then that cost should be discounted to determine its present value (see *discounting*).

Previously developed land Land that is, or was, occupied by a permanent structure (excluding agricultural or forestry buildings) and associated fixed surface infrastructure, including the curtilage of the development.

Priority substances Individual pollutants or groups of pollutants posing a significant risk to or via the aquatic environment, including waters used for the abstraction of drinking water.

Proprietary treatment systems	Subsurface and surface structures designed to provide treatment of water through the removal of contaminants. Type and design is usually specific to each manufacturer and is often covered by patents.
Public open space (POS)	The open space required under the local authority's open space and recreation standard, defined as any land laid out as a public garden or used for the purposes of public recreation. This means space that has unimpeded public access and that is of suitable size and nature for sport, active or passive recreation or children and teenagers' play. Private or shared amenity areas, for example in a development of flats or buffer landscape areas are not included as public open space.
Public sewer	A sewer that is vested and maintained by the sewerage undertaker.
Rainfall event	A single occurrence of rainfall before and after which there is a dry period that is sufficient to allow its effect on the drainage system to be defined.
Rainfall intensity	Amount of rainfall occurring in an unit of time generally expressed in mm/hr.
Rain garden	See *bioretention system*.
Rainwater butt	Small-scale garden water storage device that collects rainwater from the roof via the drainpipe.
Rainwater harvesting system	A system that collects rainwater from where it falls and stores it for use.
Recharge	The addition of water to the groundwater system by natural or artificial processes.
Recurrence interval	The average time between runoff events that have a certain flow rate; for example, a flow of 2 m/s might have a recurrence interval of two years.
Recycling	Collecting and separating materials from waste and processing them to produce marketable products.
Reduction (chemistry)	The loss of oxygen from a compound.
Reed bed	Area of grass-like marsh plants, primarily adjacent to freshwater. Artificially constructed reed beds can be used to accumulate suspended particles and associated heavy metals or to treat small quantities of partially treated sewage effluent.
Residual value	The land occupied by a system can theoretically have residual or "reclaim" value, if the function of the drainage system is no longer required at the end of the design life. In reality, however, it is generally appropriate to assume this value to be low or zero.
Resilience	The ability to recover quickly from an event or series of events.
Return period	An estimate of the likelihood of a particular event occurring. A 100-year storm refers to the storm that occurs on average once every hundred years. In other words, its annual probability of exceedance is 1% (1:100).
Rhyne	A drainage ditch or canal used to turn areas of wetland at around sea level into useful pasture.
Riffle	A rocky shoal or sandbar lying just below the surface of a watercourse.
Rill	A small, shallow channel with flowing water.
Riparian	Of, on, or relating to the banks of a natural course of water.
Risk	The combination of the probability of that potential hazard being realised, the severity of the outcome if it is, and the numbers of people exposed to the hazard.
Risk assessment	"A carefully considered judgement" requiring an evaluation of the consequences that may arise from the hazards identified, combining the various factors contributing to the risk and then evaluating their significance. It can be quantitative or qualitative.
Risk control	The definition of the measures necessary to control the risk, coupled with their implementation; the management of the risk. The risk management process must include the arrangements for monitoring the effectiveness of the control measures together with their review to ensure continuing relevance.

River basin management plan (RBMP)	A plan that sets out measures to improve water in rivers, lakes, estuaries, coasts and groundwater, within a designated river basin district as a requirement of the Water Framework Directive.
Road pavement	See *pavement*.
Runoff	Water flow over the ground surface to the drainage system. This occurs if the ground is impermeable, is saturated or if rainfall is particularly intense.
Runoff coefficient	A measure of the amount of rainfall that is converted to runoff.
Scour	Localised erosion.
Sediment	Sediments are the layers of particles that cover the bottom of water bodies such as lakes, ponds, rivers and reservoirs.
Sedimentation	The process of deposition and consolidation of suspended material carried by water, wastewater or other liquids, by gravity.
Separate sewer	A sewer for surface water or foul sewage, but not a combination of both.
Sewer	A pipe or channel taking domestic foul and/or surface water from buildings and associated paths and hardstandings from two or more curtilages and having a proper outfall.
Sewerage undertaker	A collective term relating to the statutory undertaking of water companies that are responsible for sewerage and sewage disposal, including surface water from roofs and yards of premises.
Sewer flooding	The blockage or overflowing of a sewer causing it to flood.
Sewers for Adoption	A guide agreed between sewerage undertakers and developers (through the House Builders Federation) specifying the standards to which private sewers need to be constructed to facilitate adoption.
Sewers for Scotland	The objective is the same as *Sewers for Adoption* (ie defining construction standards for drainage systems), but varying in technical legal detail.
Silt	The generic term for waterborne particles with a grain size of 4–63 µm, ie between clay and sand.
Single size grading (single size material)	The majority of the soil or aggregate particles are of one nominal size, although there may be small proportions of other sizes.
Site of special scientific interest (SSSI)	An area of land or water notified under the Wildlife and Countryside Act 1981 (as amended) as being of geological or nature conservation importance in the opinion of Countryside Council for Wales, Natural England, Scottish Natural Heritage or the Environment and Heritage Service (Northern Ireland).
Soakaway	A subsurface structure into which surface water is conveyed, designed to promote infiltration.
Soil	The terrestrial medium on which many organisms depend, which is a mixture of minerals (produced by chemical, physical and biological weathering of rocks), organic matter and water. It often contains large populations of bacteria, fungi and animals such as earthworms.
Soil moisture deficit	A measure of soil wetness, calculated by the Meteorological Office in the UK, to indicate the capacity of the soil to absorb rainfall.
Solifluction	The gradual movement of wet soil or other material.
Sorption	A physical and chemical process by which one substance becomes attached to another. It includes adsorption and absorption.
Source control	The control of runoff at or near its source, so that it does not enter the drainage system or is delayed and attenuated before it enters the drainage system.
Source protection zone (SPZ)	Areas where groundwater supplies are at risk from potentially polluting activities and accidental releases of pollutants. They are a policy tool used to control activities close to water supplies intended for human consumption.

Special area of conservation (SAC)	Established under Directive 92/43/EEC (the Habitats Directive), implemented in the UK by The Conservation (Natural Habitats, &c.) Regulations 1994 and The Conservation (Nature Habitats, etc.) Regulations (Northern Ireland) 1995. The sites are significant in habitat type and species and are considered in greatest need of conservation at a European Level. All UK SACs are based on SSSIs, but may cover several separate but related sites.
Stakeholder	Person or organisation with a specific interest (commercial, professional or personal) in a particular issue (political, regulatory, economic, financial, social, environmental etc).
Standard	Minimum performance target or level of service that SuDS designs should meet.
Storm	An occurrence of rainfall, snow or hail.
Sub-base	A layer of material on the subgrade that provides a foundation for a pavement surface.
Sub-catchment	A division of a catchment, to allow runoff to be managed as near to the source as is reasonable.
Subgrade	Material, usually natural in situ, but may include capping layer, below formation level of a pavement.
Subsidence	The vertical downward movement of a building foundation caused by the loss of support of the ground beneath the foundations.
Subsoil	The layer of soil under the topsoil on the surface of the ground. Like topsoil, it is composed of a variable mixture of small particles such as sand, silt and/or clay, but it lacks the organic matter and humus content of topsoil.
Substitution (chemistry)	The replacement of one functional group in a compound with another.
Substrate	An underlying layer; a substratum.
SuDS component	An individual element of the drainage system that conveys, stores and/or treats surface water runoff.
Sump	A pit that may be lined or unlined and is used to collect water and sediments before being pumped out.
Supplementary planning documents (SPD)	Prepared by district or unitary authorities, these documents form part of the local plan for an area. They usually provide more detail on policies in development plan documents (see *development plan*). They are not part of the formal development plan, but are a material consideration when deciding on a planning application.
Surface course	European standard description of the top layer of an asphalt pavement, currently known in UK as wearing course.
Surface water	Water bodies or flows that appear as a result of rainfall.
Surface water body	Permanent flows or bodies of water on the surface, such as lakes, rivers, streams, standing water or ponds.
Surface water runoff	See *runoff*.
Surface water sewer	An underground pipe design to convey only surface water runoff.
Suspended solids (or total suspended solids) (SS/TSS)	General term describing suspended material, used as a water quality indicator.
Sustainable drainage system (SuDS)	Drainage systems that are considered to be environmentally beneficial, causing minimal or no long-term detrimental impact.
Swale	A shallow vegetated channel designed to convey, treat and occasionally store surface water, and may also permit infiltration.
Time series rainfall (TSR)	A continuous or discontinuous record of individual rainfall events generated artificially, or selected real historical events, that are representative of the rainfall in that area.
Time of entry	Time taken for runoff from rainfall to reach an inlet into the drainage system.

Topsoil	The upper, outermost layer of soil, usually the top 5–20 cm. It has the highest concentration of organic matter and microorganisms.
Toxic material	Material capable of causing injury or death to plants and animals (including humans), especially by chemical means; poisonous.
Trash rack	Rack of bars installed to trap litter or debris to minimise risks of blockage of a conveyance path (eg pipe).
Treatment	Improving the quality of water by physical, chemical or biological means.
Tree pit	A constructed underground structure that is used to create voided space to contain a soil and/or storage volume, and protect the root system of one or more trees when located within a paved area.
Tree planter	Bioretention systems with trees planted within them to enhance their capacity and performance and/or to deliver additional amenity and biodiversity benefits.
Turbidity	Reduced transparency of a liquid, caused by the presence of un-dissolved matter.
Type 1 sub-base	Specification for the most commonly used sub-base material in conventional pavements, from the Specification for Highway Works.
Unsaturated zone	The soil layer between the land surface and the groundwater level.
Urban cooling	Reduction of the urban heat island effect (see *urban heat island effect*).
Urban creep	The increasing density of development, due to extensions, paving over of gardens and other permeable areas, and the addition or extension of roads or buildings, which increases the impermeability of developed areas and causes rates and volumes of runoff to rise.
Urban heat island effect	Where a town or city is significantly warmer than its surrounding rural areas due to human activities and the modification of land surfaces. The temperature difference is usually larger at night than during the day.
Void ratio	The ratio of open air space to solid particles in a soil or aggregate.
Volatilisation	The transfer of a compound from the solid or solution phase to the atmosphere.
Vortex flow control	The induction of a spiral/vortex flow of water in a chamber used to control or restrict the flow.
Wash-off	The transport of pollutant mass from the catchment surface during a rainfall event.
Waste	Any substance or object that the holder discards, intends to discard or is required to discard.
Wastewater	Water used as part of a process that is not retained but discharged. This includes water from sinks, baths, showers, WCs and water used in industrial and commercial processes.
Wastewater treatment works	Installation to treat and make less toxic domestic and/or industrial effluent.
Water body	A body of water forming a physiographical feature. In the WFD this covers: rivers, lakes, transitional waters, coastal waters and groundwater (aquifers).
Watercourse	A term including all rivers, streams, ditches, drains, cuts, culverts, dykes, sluices and passages through which water flows.
Water Framework Directive (WFD)	Directive 2000/60/EC of the European Parliament and Council designed to integrate the way water bodies are managed across Europe. It requires all inland and coastal waters to reach "good status" by 2015, through a catchment-based system of river basin management plans, incorporating a programme of measures to improve the status of all natural water bodies.
Water quality	The chemical, physical and biological characteristics of water with respect to its suitability for a particular purpose.
Water quality treatment volume	The permanent pond volume required to ensure that a pond provides suitable residence times of runoff, to promote contaminant reduction.

Water sensitive urban design (WSUD)	The integration of water cycle management into urban planning and design.
Water table	The point where the surface of groundwater can be detected. The water table may change with the seasons and the annual rainfall.
Weir	Horizontal structure of predetermined height to control flow.
Well	Any excavation that is drilled, cored, bored, washed, fractured, driven, dug, jetted or otherwise constructed when the intended use is for the location, monitoring, de-watering, observation, diversion, artificial recharge or acquisition of groundwater or for conducting a pumping aquifer test.
Wetland	A pond with a high proportion of shallow zones that promote the growth of bottom-rooted plants.
Wetted perimeter	The length of the line of contact between the liquid and the channel boundary at that section.
Whole life cost (WLC)	The present day value of total costs of a structure throughout its likely operating life.

ABBREVIATIONS

A	area
AA	annual average
AADT	annual average daily traffic
AAR	average annual rainfall
AC	asphalt concrete
ACI	American Concrete Institute
ACPA	American Concrete Pavement Association
AMP5	Asset management plan for the 5-year period 2010–2015
API	antecedent precipitation index
API30	30-day antecedent precipitation index
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BBA	British Board of Agrément
BCR	benefit–cost ratio
BeST	Benefits of SuDS Tool
BFIHOST	base flow index (hydrology of soil types)
BGA	British Geomembrane Association
BGS	British Geological Survey
BMP	Best Management Practice
BOD	biochemical oxygen demand
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
BS	British Standard
BSI	British Standards Institution
CAA	Civil Aviation Authority
CABE	Chartered Association of Building Engineers
CAR	Controlled Activity Regulations
$CaCO_3$	calcium carbonate
$CaSO_4$	calcium sulphate
CBGM	cement bound granular mixture
CBPP	concrete block permeable paving
CBR	Californian bearing ratio
CCTV	closed-circuit television
CDM	Construction (Design and Management) Regulations (2015)
CE	Conformité Européene
CEA	cost-effectiveness analysis
CEH	Centre for Ecology and Hydrology (formerly Institute of Hydrology)

CEN	Comité Européen de Normalisation (European Committee for Standardization).
CESWI	Civil Engineering Specification for the Water Industry
CGA	coarse-graded aggregate
CIHT	Chartered Institute of Highways and Transportation
CIRIA	Construction Industry Research and Information Association
CIWEM	Chartered Institution of Water and Environmental Management
CLG	Communities and Local Government
CMHC	Canada Mortgage and Housing Corporation
CO_2	carbon dioxide
COD	chemical oxygen demand
CPSA	Concrete Pipeline Systems Association
CPTED	crime prevention through environmental design
CRMCA	Colorado Ready Mixed Concrete Association
CRoW	Countryside and Rights of Way (Act, 2000)
CRWA	Charles River Watershed Association
CSO	combined sewer overflow
CV	contingent valuation
CWI	catchment wetness index
D	1 demand 2 storm duration
DA	drainage assessment
DBM	dense bitumen macadam
DCLG	Department for Communities and Local Government
DDF	depth-duration-frequency
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DEP	Department of Environmental Protection (Pennsylvania)
DETR	(the former) Department for Environment, Transport and the Regions
DfT	Department for Transport
DiBT	Deutsches Institut fur Bautechnik
DMRB	Design Manual for Roads and Bridges
DoE	(the former) Department of the Environment
DoP	declaration of performance
DTLR	(the former) Department for Transport, Local Government and the Regions
DW	dry weight
DWS	drinking water standard
EA	Environment Agency (England)
EbD	enquiry by design
EC	European Commission electrical conductivity

EHSNI	Environment and Heritage Service Northern Ireland
EIA	Environmental Impact Assessment
EMC	event mean concentration
EPDM	ethylene propylene diene monomer rubber
EPA	Environmental Protection Agency
EQS	environmental quality standard
EQSD	Environmental Quality Standards Directive (2008/105/EC)
ETA	European Technical Assessment
EU	European Union
FARL	flood attenuation from reservoirs and lakes
FAWB	Facility for Advancing Water Biofiltration (Australia)
FCA	Flood Consequence Assessment (Wales)
FCERM	flood and coastal erosion risk management
FEH	Flood Estimation Handbook (developed by CEH, published in 1999)
FLL	Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (The Landscape Research, Development and Construction Society, Germany)
FOS	factor of safety
FRA	Flood Risk Assessment
FSR	flood studies report
FSSR	flood studies supplementary report
FWMA	Flood and Water Management Act (2010)
GBR	general binding rules
GCL	geocomposite clay liners
GIS	geographic information system
GP3	Groundwater projection: principles and practice (Environment Agency, 2013)
GRO	Green Roof Organisation
GRP	glass-reinforced plastic
GSA	General Services Administration (USA)
h	hydraulic head
h_{max}	maximum depth of water that will occur in the storage medium
HA	Highways Agency
HAWRAT	Highways Agency Water Risk Assessment Tool
HBCGA	hydraulically bound coarse graded aggregate
HC	hydrocarbons
HCA	Homes and Communities Agency
HDPE	high density polyethylene
hEN	Harmonised European Standard
HGV	heavy good vehicle
HMSO	Her Majesty's Stationery Office
HOST	hydrology of soil types

HSE	Health and Safety Executive
i	rainfall intensity
ICE	Institute of Civil Engineers
ICPI	Interlocking Concrete Pavement Institute
IDB	internal drainage board
IF	effective paved area factor
IGS	International Geosynthetics Society
IoH (or IH)	Institute of Hydrology (now Centre for Ecology and Hydrology)
ISO	International Organization for Stardardization
IUCN	International Union of Conservation of Nature
JCLI	Joint Council for Landscape Industries
JNCC	Joint Nature Conservation Committee
k	coefficient of permeability
LA	local authority Los Angeles (as in the LA test)
LHA	local highway authority
LMP	landscape management plan
LNAPL	light non-aqueous phase liquid
LPA	Local planning authority
LTS	Long-Term Storage
LUPI	land use pollution index
LUST	land use surface type
M5-2d	2 day rainfall of 5 year return period (mm)
M5-60	60 minute rainfall of 5 year return period (mm)
MAC	maximum allowable concentration
MCA	multi-criteria analysis
MCERTS	monitoring certificate scheme
MCHW	Manual of Contract Documents for Highway Works
MD	micro deval
MDR	minimum design requirement
MPPS	macro pervious surfaces
MTBE	methyl tert-butyl ether
MWHC	maximum water holding capacity
n	1 porosity 2 Manning's coefficient
NAPI	normalised antecedent precipitation index (see *API30*)
NBS	National Building Specification
NERC	Natural Environment Research Council
NHBC	National House Builders Council
NIEA	Northern Ireland Environment Agency

NJCAT	New Jersey Corporation for Advanced Technology
NJUG	National Joint Utilities Group
NNSS	Non-Native Species Secretariat
NPK	nitrogen-phosphorous-potassium
NPS	national plant specification
NPV	net present value
NRSWA	New Roads and Street Works Act (1991)
NRW	Natural Resources Wales
O_2	oxygen
ODPM	(the former) Office of the Deputy Prime Minister
OLA	Occupiers' Liability Act (1957 and 1984)
OMOE	Ontario Ministry of the Environment
ONS	Office of National Statistics
P	perimeter
PAH	polycyclic aromatic hydrocarbon
PAS	publicly available specification
PE	polyethylene
PF	soil moisture depth
PI	pollution index
PIMP	percentage impermeability
POS	public open space
PP	polypropylene
PPC	pollution prevention and control
PPE	personal protective equipment
PPG	pollution prevention guidelines
PR	percentage runoff
PRE	public rescue equipment
PSD	particle size distribution
PV	present value
PVC	polyvinyl chloride
PVC-U	polyvinyl chloride (unplasticised)
q	infiltration rate
Q	flow rate
QA	quality assurance
Q_{BAR}	the (arithmetic) mean annual maximum flood (m3/s)
RE	risk element
REC	river ecosystem class
ReFH	revitalised flood hydrograph
RHS	Royal Horticultural Society
RIBA	Royal Institute of British Architects

RoSPA	Royal Society for the Prevention of Accidents
RS	risk score
RSPB	Royal Society for the Protection of Birds
RVTS	roadside vegetated treatment sites
RWH	rainwater harvesting
S	slope
SAAR	Standard Average Annual Rainfall (mm)
SAC	Special Area of Conservation
SCOTS	Society of Chief Officers of Transport in Scotland
SED	special engineering difficulties
SEPA	Scottish Environment Protection Agency
SHW	Specification for Highway Works
SISG	Site Investigation Steering Group
SINC	site of importance for nature conservation
SMD	soil moisture deficit
SOM	soil organic matter
SPD	supplementary planning document
SPI	site pollution index
SPR	standard percentage runoff
SPRHOST	HOST related standard percentage runoff (see *HOST*)
SPZ	source protection zone
SRN	strategic road network
SSSI	site of special scientific interest
STEM	science, technology, engineering and maths
STEP	Sustainable Technologies Evaluation Program
SuDS	sustainable drainage system
SWM	surface water management
T	return period for storm event
TAN15	Technical Advice Note 15 Development and flood risk (Welsh Government, 2004)
TDAG	Trees and Design Action Group
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TPO	tree preservation order
TRCA	Toronto and Region Conservation Authority
TRL	Transport Research Laboratory (formerly Transport and Road Research Laboratory, TRRL; and Road Research Laboratory, RRL)
TSR	time series rainfall
TSS	total suspended solids
TWI	The Welding Institute
UCWI	urban catchment wetness index

UKAS	UK Accreditation Service
UKCP09	UK Climate Projections 2009
UKWIR	UK Water Industry Research
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USEPA	United States Environmental Protection Agency
UV	ultraviolet
V	1 velocity 2 storage volume
VSC	storage required for surface water management
Vt	water quality treatment volume
WaPUG	Wallingford Procedure Users Group (superseded by the CIWEM Urban Drainage Group)
WHS	Wallingford HydroSolutions
WIS	Water Industry Specification
WF	weighting factor
WFD	Water Framework Directive (2000/60/EC)
WLC	Whole life cost
WRAP	1 winter rainfall acceptance potential 2 Waste and Resource Action Programme
WSUD	water sensitive urban design
WWT	Wildfowl & Wetlands Trust
Y	yield
YR	runoff yield
η	hydraulic filter efficiency (ratio)
µm	micrometre (ie 1×10^{-6} m)

Image courtesy Simon Bunn

APPENDIX B CHECKLISTS

Contents

Appendix B Checklists

This appendix provides a series of checklists that can be used by designers or drainage system approving bodies to ensure that all relevant design, construction and maintenance considerations have been taken into account and documented in a consistent way.

B.1 SUDS DESIGN AND LAND USE PLANNING SUBMISSIONS

The SuDS design process is set out in **Chapter 7**, including the integration and links with the (land use) planning process.

Each stage of the planning process will require a different level of submission detail in terms of the design of the surface water management system, but the issues are relevant for all scales of development. The following three subsections include guidance and checklists relevant to each of the key stages that could be used by the planning authority or the organisation responsible for drainage approval and adoption in their consultation and planning process.

The scale of the submissions will be dependent on the scale of the development site and the level of potential environmental risk posed by the surface water management system. The proposed checklists will ensure that all issues have been considered at the correct stage of planning. However, for small sites, many of the items may not be relevant, or may only require cursory consideration. As indicated in **Chapter 7, Figure 7.2**, the outline planning stage may not be required for small sites, and for many sites the Flood Risk Assessment may include the conceptual drainage design strategy.

Where earlier stages are omitted, the submission requirements for that stage should be included for consideration at subsequent stages to ensure that the planning process for the system has taken all aspects into consideration.

B.1.1 Pre-application

Developers should engage in pre-application discussions with the drainage system approving body, either directly or as part of a multi-disciplinary team involved with the planning application to the local planning authority. Effective pre-application discussions and master planning should ensure a robust, viable and cost-effective scheme from the outset, where the development objectives are informed by the surface water management strategy, and vice versa

For larger sites or multi-plot developments, where the land is subdivided into separate plots owned by different landowners, or where there is an intention to develop the land in phases, the specification for a drainage master plan should be agreed at this stage. The master plan should be designed to ensure effective communication between all developers and identified stakeholders in establishing the selection, implementation and phasing of source control, site and regional SuDS components. It should also set out the responsibilities for, delivery of and maintenance of temporary site drainage measures required during the construction process.

Table B.1 provides a checklist of information that should be provided and agreed between all parties at the pre-application stage.

TABLE B.1 Suggested pre-application discussion material

Ref	Requirements	Details (or reference documentation)	Accepted?
(a)	Any planning and environmental objectives for the site that should influence the surface water management strategy – these objectives can be put forward by both the developer and the approving body/LPA and should be agreed by all parties		
(b)	The likely environmental or technical constraints to SuDS design for the site – these should be agreed by all parties		
(c)	The requirements of the local SuDS approval and adoption processes. These should be provided to the developer by the drainage approving body		
(d)	The suite of design criteria to be applied to the SuDS scheme (taking account of (a) to (c))		
(e)	Evidence that the initial development design proposals have considered the integration and linkage of the surface water management with street layouts, architectural and landscape proposals		
(f)	An assessment of strategic opportunities for the surface water management system to deliver multiple benefits for the site – this should be provided by the developer and should include the strategic use of public open space for SuDS		
(h)	The statutory and recommended non-statutory consultees for the design proposals – this should be provided by the approval body or LPA		
(i)	The likely land and infrastructure ownership for drainage routes and points of discharge (including sewerage assets)		
(j)	An assessment of statutory consultee responsibilities and requirements, including timescales for any likely required approvals/consents		
(k)	Any potential local community impacts, health and safety issues or specific local community concerns and drainage approving body requirements that should be addressed by the detailed design		
(m)	An assessment of cost implications of stakeholder obligations		
(n)	An agreed approach to the design and maintenance of the surface water management for the proposed site		

Note

All of the above should be agreed (where relevant) with the LPA, internal drainage board, environmental regulator, water companies and sewerage undertakers. The SuDS planning process should be closely linked to the development planning process, and the drainage design should be integrated where possible within the design of the development as a whole.

B.1.2 Outline planning

If an outline planning application is to be submitted to the local planning authority, the developer should include a conceptual suds design strategy which can be reviewed by the drainage approving body and their consultees, or others affected by the proposals (eg the local planning authority, environmental regulator and the water and sewerage company). For some developments, this conceptual strategy may form part of the FRA/FCA for the site.

Where a drainage master plan (or site surface water drainage strategy) is required or conditioned, at this stage (for larger sites) this should also include:

- details of the proposed phasing of the SuDS system
- individual plot discharges and storages
- definition of responsibilities for construction, maintenance and adoption of each element of the scheme.

Table B.2 provides a checklist that can be used to document and verify that the relevant information has been provided. Note that if a pre-application consultation has been undertaken, much of the material should have been agreed at that stage.

This information is required to be provided in the form of a report, together with appropriate plans.

TABLE B.2 Conceptual drainage design documentation suggested for submission at outline planning

Ref	Requirements	Details (or reference documentation)	Accepted?
(a)	Definition of the natural drainage characteristics within, and hydrologically linked to, the site and demonstration that the drainage proposals will integrate with and not compromise the function of the natural drainage systems – natural flow paths for surface water runoff should be identified on a plan where appropriate		
(b)	Definition of state, performance and ownership of any existing site surface water drainage infrastructure and demonstration that the drainage proposals consider, use or protect these systems (where appropriate)		
(c)	Proposed strategic approach to managing on-site flood risk from all sources (as part of or in alignment with the Flood Risk Assessment/flood consequences assessment), and implications of existing flood risk for proposed SuDS design		
(d)	Outline assessment of existing geology, ground conditions (including contamination and stability) and permeability through desk-based research (eg a review of geological/hydrogeological maps, infiltration potential maps and site visit observations) – to determine the suitability of infiltration drainage for the site runoff. Infiltration tests should be carried out at this stage wherever possible. If infiltration is proposed but tests are not available an alternative outfall should be identified in case future tests show that infiltration is not possible		
(e)	Identification of the requirements of any environmentally sensitive potential receiving water bodies for the runoff (eg groundwater protection zones, archaeological features, receiving water body environmental designations)		
(f)	The impact of any stakeholder engagement on the design and proposed community engagement plans		
(g)	Confirmation of discharge points (ie to ground, watercourse or public sewer) for all return period events		
(h)	Confirmation of the design criteria for the SuDS system (including an assessment of the need and opportunity for rainwater harvesting and use), including climate change and urban creep allowances		
(i)	Conceptual SuDS design including Interception, treatment, conveyance, peak flow and volume control, storage and exceedance routes and components (and demonstration that required indicative storages and conveyance flows can be delivered on site)		

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TABLE B.2 Conceptual drainage design documentation suggested for submission at outline planning

Ref	Requirements	Details (or reference documentation)	Accepted?
(j)	Proposed multi-functional use of SuDS space to meet community and environmental requirements (where possible green infrastructure) and the potential contribution of the surface water management system (eg BREEAM Community, DCLG, 2008, and Birkbeck and Kruczkowski, 2012) to the development design objectives for sustainability (including climate resilience)		
(k)	Proposed split of the SuDS between private and public		
(l)	Confirmation of approval and adoption arrangements for all SuDS components		
(m)	Details of any required off-site works and consents		
(n)	Appropriate consideration of the maintainability of the proposed SuDS		
(o)	Appropriate consideration of the constructability of the proposed SuDS (including the requirements for phasing or protection of components)		
(p)	An initial health and safety risk assessment		

B.1.3 Full planning (or reserved matters)

The developer will be required to submit a detailed drainage submission to the drainage approving body, to be considered alongside the planning application. The final submission on the detailed design and layout of the surface water management system should update and enhance the conceptual SuDS strategy and any surface water management master plan for the site and should be in line with any conditions set by the outline planning application.

All relevant statutory and identified non-statutory stakeholder consultations should be undertaken and taken into account when putting together the final proposals.

Table B.3 provides a checklist that can be used to document and verify that the relevant information has been provided.

TABLE B.3 Detailed drainage design documentation suggested for submission at full planning

Ref	Requirements	Details (or reference documentation)	Accepted?
(a)	Where infiltration is proposed, an acceptable Infiltration Assessment has been submitted, including any geotechnical test results and evaluations		
(b)	A scheme design assessment with appropriate supporting calculations that has been submitted that demonstrates design conformity with the required design criteria for the site; justification of any non-compliance to national or locally set standards		
(c)	Plans of the proposed drainage system, showing: ▪ drainage catchment and sub-catchment areas (including impermeable and permeable zones, and any phasing details) ▪ existing and proposed site sections and levels ▪ long- and cross-sections for the proposed drainage system (including exceedance flow management routes) and final building finished floor levels ▪ details for connections to watercourses and sewers ▪ maintenance access and any arisings storage and disposal arrangements ▪ operational characteristics of any mechanical features		
(d)	All necessary consents required for off-site works		
(e)	Commitments for approval and adoption arrangements for all elements of the system (including exceedance flow management components); commitments to any cost contributions, valuation and security of any required non-performance bond		
(f)	Appropriate consideration and management of any health and safety issues relating to SuDS implementation		
(g)	The design of each element undertaken in accordance with best practice (using detailed design checklists, where required)		
(h)	Specifications prepared and approved for all materials used in the design		
(i)	A construction method statement for the proposed SuDS system submitted including: ▪ construction processes to protect the SuDS functionality (including the provision of any required temporary drainage systems) ▪ programming to protect the SuDS functionality ▪ landscape planting ▪ consideration of access for inspections by the approving or adopting organisation		

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TABLE B.3 Table B.3 Detailed drainage design documentation suggested for submission at full planning

Ref	Requirements	Details (or reference documentation)	Accepted?
(j)	A Maintenance Plan for the proposed SuDS submitted including: ▪ a description of the system and how each part of the system is expected to work ▪ management objectives for the site ▪ inspection and maintenance schedules, material, tools and initial cost estimates ▪ maintenance access points, easements and outfalls		
(k)	An information and communications plan for the proposed SuDS scheme submitted, where appropriate, including: ▪ communication with and education of existing residents ▪ communication with and education of new residents ▪ site and SuDS component specific information boards ▪ local community education and education strategies (eg through schools). Note: this is only likely to be required on larger sites and may be provided by the drainage approving body or the developer (to be agreed between them)		

B.2 SCHEME DESIGN CHECKLIST

Table B.4 provides a checklist that should be used when assessing the design of a proposed SuDS scheme for approval. It encourages a consistent assessment of the scheme against the criteria and standards set out in this manual.

This checklist will need to be supported by:

- a scheme health and safety risk assessment (**Section B.3**)
- detailed infiltration assessment (if infiltration components form part of the scheme) (**Section B.4**)
- detailed design checks for the proposed SuDS components (**Section B.5**)
- a construction method statement for the scheme (**Section B.6**)
- a Maintenance Plan for the scheme (**Section B.8**).

Table B.4 could be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it could be used as part of the required submissions from the developer.

TABLE B.4 Scheme design assessment checklist

Requirements						
Site ID						
Site location and co-ordinates						
Site description		Drawing reference(s)				
Date of assessment		Specification reference				
Type of development		Site area				
		SuDS manual section	**Y**	**N**	**Summary of details**	**Comments/remedial actions**
Water quantity						
Is surface water used as a resource, where appropriate?		3.2.2				
Does the design meet the following discharge hierarchy (with acceptable justification for moving between levels): 1 infiltration to the maximum extent that is practical – where it is safe and acceptable to do so 2 discharge to surface waters 3 discharge to surface water sewer 4 discharge to combined sewer (last resort)		3.2.3				
If infiltration is used: confirm that an acceptable infiltration assessment has been undertaken and submitted						
If discharge to a sewerage asset is proposed, has evidence been provided that the design criteria have been agreed with the sewerage undertaker and that an appropriate connection detail has been agreed?						
Has runoff and flooding from all sources (both on and off site) been considered and taken into account in the design?		3.3.3				
Does the scheme design demonstrate on-site retention of approximately the first 5 mm of runoff from impermeable surfaces for most events? How is Interception to be delivered (eg infiltration, green roofs, permeable pavements, vegetated surfaces, bespoke design – provide details)?		3.3.1 4.3.1				

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TABLE B.4 Scheme design assessment checklist

Requirements					
Does the design demonstrate adequate control of the 1 year, critical duration site event?	3.2.3 3.3.2				
Does the design demonstrate adequate control of the 100 year, critical duration site event (including urban creep and climate change allowances)?	3.2.3 3.2.7 3.3.2				
Does the design demonstrate adequate control of the 100 year, 6 hour runoff volume from the site?	3.2.3 3.3.1				
Are any natural hydrological features on the site adequately protected by the design?	3.2.4				
Are all SuDS components outside any areas of significant flood risk? If not, provide justification and evidence that the risks to system performance are acceptable	3.2.5				
Is pumping a requirement for the operation of the system? If yes, have all other possible alternatives been considered appropriately?	3.2.5				
Have infiltration rates, hydraulic gradients and any downstream constraints been evaluated to ensure that the components will drain down within a suitable timescale?	3.2.5				
Are flows up to the agreed standard of service event (including allowances for urban creep and climate change) fully conveyed within the drainage system?	3.2.6 3.2.7 3.3.3				
Are flows up to the agreed exceedance standard of service event (including allowances for urban creep and climate change) contained or stored on site within safe exceedance storage areas and flow paths? Are these areas and flow paths protected from future development?	3.2.6 3.2.7 3.3.3				
Water quality					
Does the design include an appropriate treatment strategy to ensure that: ▪ sediment is trapped and retained on site in accessible and maintainable areas? ▪ suitable SuDS components have been provided in series before discharge that provide acceptable treatment, taking account of proposed site land use and the status of all receiving water bodies?	4.2.2 4.3.2				

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TABLE B.4 Scheme design assessment checklist

Has consideration been given to the potential implications of climate change on the capability of the SuDS components to provide the required treatment?	4.2.3				
Requirements					
Amenity criteria					
Where the drainage system serves more than one property, is public space used and integrated with the drainage system in an appropriate and beneficial way?	5.2.2				
Does the proposed scheme enhance the visual character of the development?	5.2.3				
Are the proposed components safe for any proposed amenity use? Has a health and safety risk assessment been undertaken?	5.2.4 Chapter 36 Checklist B.3				
Have opportunities been taken to use the drainage system to enhance development resilience to future climate change scenarios?	5.2.5				
Is the structure and function of the drainage system clear and obvious to the local community?	5.2.6				
Do the design proposals include sufficient provision for community engagement and awareness raising?	5.2.7				
Biodiversity criteria					
Will the drainage system support and protect natural local habitats and species?	6.2.1				
Will the drainage system contribute to the delivery of local biodiversity objectives?	6.2.2				
Does the design support local (and wider where possible) habitat connectivity?	6.2.3				
Does the design promote the creation of diverse, self-sustaining and resilient ecosystems?	6.2.4				
Constructability					
Has an acceptable construction method statement been submitted and approved?	Chapter 31				

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TABLE B.4 Scheme design assessment checklist

Maintainability					
Are the design features sufficiently durable to ensure structural integrity over the system design life, with reasonable maintenance requirements?	Chapter 32				
Requirements					
Are the operating and maintenance requirements of the drainage system adequately defined?	Chapter 32				
Has an acceptable Maintenance Plan been submitted and approved?	Chapter 32				
Cost-effectiveness					
Is operation and maintenance achievable at an acceptable cost to the adopting body (including any pumping requirements)?	Chapter 35				
Safety					
Are the proposed components safe to construct, maintain and operate? Has a health and safety risk assessment been undertaken?	Chapter 36 Checklist B.3				

System design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

B.3 SUDS HEALTH AND SAFETY RISK ASSESSMENT CHECKLIST

Table B.5 provides a checklist that can be used as part of a risk assessment to document and verify that relevant health and safety hazards have been identified, considered and managed. It should be expanded or amended to ensure that it is relevant to site specific scenarios and that all potential hazards are included. Guidance on health and safety risk management is provided in Chapter 36.

TABLE B.5 SuDS health and safety risk assessment checklist

Site/system overview	
Site ID	
Asset ID	
Location	
SuDS component	
Assessment date	
Date of next assessment	
1 Establish context	
General description of component and its operation	
2 Identify potential hazards	Are hazards present? (Y/N)
Drowning or falling through ice in winter	If YES complete Section 3
Slips, trips and falls	If YES complete Section 4
Entry into pipes or confined spaces (note this is for inadvertent public access; follow relevant legislation and guidance for worker access)	If YES complete Section 5
Water quality – health risk	If YES complete Section 6

continued...

TABLE B.5 SuDS health and safety risk assessment checklist

3 Drowning or falling through ice in winter		
Consider factors that might affect: • **the likelihood of people entering the water/accessing the ice** • **the potential consequence of entering the water/accessing the ice**	**Summary of influence of factor on likelihood of entry/access, including justification (consider for children < 5 years, children ≥ 5 years, adults)**	**Summary of influence of factor on consequence of entry or access, including justification (consider for children < 5 years, children ≥ 5 years, adults)**
Environmental factors		
Proximity to populated areas: schools, inns, retail/tourism, picnic areas, play areas, car park, roads, especially attractive features likely to be visited		
Features allowing or encouraging access (eg paths)		
Physical accessibility of proposed drainage feature: consider intended use and inadvertent access (including of small children)		
Visibility and natural surveillance of proposed drainage features		
Behavioural factors		
Category and volume of expected users: swimmers, anglers, walkers, drivers, specialist water users, General public, dog walkers, teenagers, accompanied/unaccompanied children		
Nature of development (housing, commercial, industrial etc)		
Any known existing risks (eg records of accidents) posed by water/ drainage features at or close to the site?		
Design factors – water's edge		
Type and nature of water-edge planting		
Definition of water edge and nature of ground (eg soft/hard)		
Natural obstacles, barriers/fencing		
Height of edge above water		
Gradient and extent of slopes above, at and below water level		

Note

For definition of levels, see Table 36.2 in Chapter 36.

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TABLE B.5 SuDS health and safety risk assessment checklist

3 Drowning or falling through ice in winter		
Consider factors that might affect: • **the likelihood of people entering the water/accessing the ice** • **the potential consequence of entering the water/accessing the ice**	**Summary of influence of factor on likelihood of entry/access, including justification (consider for children < 5 years, children ≥ 5 years, adults)**	**Summary of influence of factor on consequence of entry or access, including justification (consider for children < 5 years, children ≥ 5 years, adults)**
Design factors – water body		
Water depth profile		
Water surface area		
Clarity		
Underwater obstacles or traps		
Potential currents, velocities		
Potential increase in depth of water and rate of rise		
Potential for ice formation and significant depth of water below in winter		
Public education		
Signage		
Community engagement strategies		
Local education strategies (eg schools)		
Overall assessment of likelihood of entry/access and consequences	**Likelihood**	**Consequences**
Children < 5 years Children > 5 years Adults		

Summary of section 3 risk assessment for drowning or falling through ice						
Group	**Likelihood of entry to water**	**Likely consequence of entry to water**	**Overall level of risk posed by the design[1]**	**Further mitigation measures required**	**Action date**	**Final level of risk[1]**
Children < 5 years Children > 5 years Adults						

Note

For definition of levels, see Table 36.2 in Chapter 36.

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TABLE B.5 SuDS health and safety risk assessment checklist

4 Slips/trips/falls		
Factors that might affect likelihood of people slipping/tripping/falling	**Summary of influence of factor on likelihood of slip/trip/fall, including justification (consider for children < 5 years, children ≥ 5 years, adults)**	**Summary of influence of factor on consequence of slip/trip/fall, including justification (consider for children < 5 years, children ≥ 5 years, adults)**
Design factors – inlets and outlets or channels		
Headwall or channel location		
Headwall height or channel depth and width		
Slope of headwall or channel profile		
Channels – profile and risk of freezing water		
Design factors – surfaces		
Level changes		
Surfacing materials		

Summary of section 4 risk assessment for slips/trips/falls						
Group	**Likelihood of slips/trips/falls/ other injury**	**Likely consequence of slips/trips/falls/ other injury**	**Overall level of risk posed by the design[1]**	**Further mitigation measures required**	**Action date**	**Final level of risk[1]**
Children < 5 years Children ≥ 5 years Adults						

Note

For definition of levels, see **Table 36.2 in Chapter 36**.

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TABLE B.5 SuDS health and safety risk assessment checklist

5 Entry into pipes or confined spaces (Note: This risk assessment covers inadvertent access by the public. Where specific access is required by workers the requirements of relevant health and safety legislation and guidance should be followed.)		
Factors that might affect likelihood of people entering pipes or confined spaces	**Summary of influence of factor on likelihood of entry into pipes or confined spaces, including justification (consider for children < 5 years, children ≥ 5 years, adults)**	**Summary of influence of factor on consequence of entering pipe or confined space, including justification (consider for children < 5 years, children ≥ 5 years, adults)**
Design factors – inlets and outlets		
Pipe diameter		
Are grilles provided?		
Design factors – chambers		
Depth of chamber		
Is access possible?		

Summary of section 5 risk assessment for entry into pipes/confined spaces

Group	Likelihood of entry into pipes/ confined spaces	Likely consequence of entry into pipes/ confined spaces[1]	Overall level of risk posed by the design	Further mitigation measures required	Action date	Final level of risk[1]
Children < 5 years Children ≥ 5 years Adults						

Note

For definition of levels, see **Table 36.2 in Chapter 36**.

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TABLE B.5 SuDS health and safety risk assessment checklist

6 Health issues		
Factors that might affect likelihood of people suffering from ill health due to SuDS water quality	**Summary of influence of factor on likelihood of poor health, including justification (consider for children < 5 years, children ≥ 5 years, adults)**	**Summary of influence of factor on consequence of resulting ill health, including justification (consider for children < 5 years, children ≥ 5 years, adults)**
Pollution treatment strategy		
Level of contamination of publically accessible water		
Likely contamination from rat urine		
Likely contamination from dog or bird fouling		
Likelihood of toxic algal blooms		
Likelihood of vectors (organism which carries disease-causing microorganisms from one host to another)		
Public accessibility to any sediment accumulation zones		
Public education and risk management		
Signs		
Community engagement strategies		
Local education strategies (eg schools)		
Litter management and control		
Dog fouling management and control		

Summary of section 5 risk assessment for health issues						
Group	**Likelihood of ill health**	**Likely consequence of ill health**	**Overall level of risk posed by the design**	**Further mitigation measures required**	**Action date**	**Final level of risk**
Children < 5 years Children ≥ 5 years Adults						

Note

For definition of levels, see **Table 36.2 in Chapter 36**.

B.4 INFILTRATION ASSESSMENT

B.4.1 The benefits and suitability of infiltration

The use of infiltration to dispose of surface water runoff has a number of important benefits:

- It can reduce the volume of runoff and the storage required to control peak rates of runoff discharged from the site (and thus help deliver important flood risk management criteria).
- It can help replenish aquifers local to the site through deep infiltration, and/or act to support local river base flows and wetland systems via shallow infiltration processes.
- It can help support local soil moisture levels and vegetation.

These benefits mean that infiltration is advocated as the first route of disposal of surface water runoff to be considered when developing runoff management options by many national guidance documents, including this manual and HM Government (2010). Detailed guidance on infiltration testing and infiltration system design can be found in **Chapter 25**.

Infiltration can be used in the following ways:

- As a destination for the disposal of surface water runoff for design events

  Limited infiltration capacity may mean that infiltration is used for small and/or medium events and then may work in combination with discharge to surface waters for more extreme events.
- To help provide Interception for a sustainable drainage system with an outfall to a watercourse or sewer

  Interception is concerned with preventing runoff from the site for the first 5 mm (or other specified depth) of rainfall for most events (note: it is not expected that Interception will necessarily be delivered for all events, eg when soils are saturated following prolonged heavy rainfall). The delivery of Interception ensures that the runoff frequency from the site more closely mimics greenfield characteristics, and constrains the number of potentially polluting discharge events. Interception does not necessarily need a specific infiltration capacity, but most soils (even capping layer soils on contaminated sites) should provide some Interception if covered with a layer of topsoil. To deliver Interception, it should be demonstrated that the system can remove the specified Interception rainfall depth within 48 hours through the use of evaporation, evapotranspiration and infiltration processes.

There are, however, a number of scenarios where infiltration may not be possible or cannot be relied on as a complete discharge route for all sizes (return periods) of event. These caveats are important and it should not therefore be interpreted that infiltration must be used at all cost and rather, that infiltration should be used where conditions allow and where it is safe.

The following considerations should be fully evaluated before determining the extent to which infiltration can be used on a site:

- the infiltration capacity of the soil
- the risk of ground instability or subsidence due to infiltration
- the risk of slope instability or solifluction as a results of infiltration
- the risk of pollution from mobilising existing contaminants on the site
- the risk of pollution from infiltrating polluted surface water runoff from the site
- the risk of groundwater flooding due to infiltration
- the risk of groundwater leakage into the combined sewer owing to promoting infiltration on the site.

Infiltration may be at or near the surface and spread over a wide area (eg basin), or it could be a point location such as a normal soakaway. Many sites will use normal small soakaways for roof water where possible. The issues listed above become more of a risk the more any water is concentrated into a point discharge. Thus, large-volume deep soakaways pose more of a risk than small shallow basins, for example.

Preliminary information on whether a site may be suitable for infiltration, or to identify issues that should be considered, can be obtained from the British Geological Survey (BGS) Infiltration SuDS Map. This map allows users to determine the:

- likely presence of constraints that ought to be considered when planning infiltration SuDS
- likely potential for the ground to accept infiltration
- likely potential for ground instability when water is infiltrated
- likely issues around groundwater quality protection.

The acceptability of infiltration with respect to groundwater protection and system design methods is presented in **Chapters 4 and 26**.

B.4.2 The objectives of the checklist

This infiltration assessment checklist is intended to be used by organisations approving the drainage scheme (drainage approving bodies) to help assess submissions for drainage approval that include infiltration systems. As discussed above there may be scenarios that preclude infiltration as the main outfall for surface water. If it can be shown that infiltration is not suitable for the main destination for surface water from a site (eg because of the presence of contamination that could be mobilised and could pose a risk to groundwater or other receptors) then completing this checklist is not necessary and infiltration tests will not be required. On marginal sites where it is not clear whether infiltration is possible or not, infiltration tests may be necessary to show that infiltration cannot be relied upon as the main outfall for surface water.

It is intended to facilitate a consistent assessment process and to ensure that designs meet the key design requirements set out in this manual.

It is also intended to help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

The use of infiltration should be approved by a geotechnical engineer or engineering geologist (eg a registered ground engineer adviser or similar):

- on larger sites or sub-catchments (> 1000 m^2 draining to an infiltration device)
- in areas where there are likely to be issues with the use of infiltration (eg due to potential solution features)
- where the consequences of failure are significant (eg damage to buildings).

This requirement is particularly important where infiltration tests have not been undertaken by a specialist site investigation company. Normally, a company carrying out site investigations and infiltration tests will include a geotechnical engineer or engineering geologist, and they can advise of any potential significant issues and advise on the suitability of infiltration and any constraints that should be applied to a site. This can be included in the report provided by the specialist company for very little cost.

If infiltration is proposed at conceptual design stage and there are no infiltration test results available, alternative proposals for discharge should be provided so that in the event that infiltration tests show that infiltration is not possible, the site can still be effectively drained.

The infiltration checklist can be applied to all sites. However, for lower risk situations, approving authorities may wish to reduce the extent of the checklist. This will be a decision made by individual authorities based on their knowledge of local conditions. Such cases could include the following, subject to there being no significant geotechnical, contamination or groundwater flooding issues in the area in which the site is located:

- less than ten properties with individual soakaways for roof drainage with each soakaway draining less than 100 m^2 of roof area
- small car parks or similar areas less than 1000 m^2.

This checklist is designed to be used for sites where infiltration is a significant destination for surface water. It is not intended to be used for sites where infiltration will only be used to help provide Interception (eg water leaking from the base of swales or basins). Some of the items discussed may need to be considered when deciding if any infiltration is acceptable (eg where there are risks of mobilising contamination in the subsoils).

TABLE B.6 Infiltration assessment checklist

Requirements	
Site ID	
Asset ID	
Infiltration component location	
Infiltration component type	

Infiltration capacity	**Details**	**Acceptable submission?**	**Further requirements**
Confirm that infiltration test results have been provided, along with trial pit records with soil/rock descriptions of the materials in which the test has been completed in accordance with BS EN ISO 14688-1:2002+A1:2013 or BS EN ISO 14689-1:2003			
Confirm that the infiltration tests have been undertaken at the location, depth and with a head of water that replicates the proposed design			
Confirm that infiltration tests state which stratum the results are appropriate to and any limitations in the test. For example, has the infiltration rate been estimated by assuming water only infiltrates into one particular stratum such as a discrete layer of limestone?			
Confirm that the infiltration tests follow BRE (1991) or Bettess (1996) as far as is relevant to the design. If not, state what variations have been made to the test and why			
Confirm that the head of water in the infiltration test falls to less than 25% of the initial head of water. (Note: if this does not occur the results should not be extrapolated – the results should state "Infiltration test cannot be determined.")			
Confirm that account has been taken of the soil descriptions and an assessment of the likely impact of water on the soil and long-term infiltration rate has been included (eg high initial infiltration rates in dry mudstone may not be representative of long-term values when soaking water has caused weathering)			

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TABLE B.6 Infiltration assessment checklist

Infiltration capacity	Details	Acceptable submission?	Further requirements
Confirm what measures are necessary to prevent construction activities (especially compaction) changing the infiltration characteristics			
Confirm that the test infiltration capacity is likely to be representative of the wider ground mass (eg the test has not been undertaken in a limited extent of sand within a mass of clay)			
Groundwater levels			
Confirm that evidence has been provided of groundwater levels and seasonal variations (eg via relevant groundwater records or on-site monitoring in wells)			
Confirm that the maximum likely groundwater levels are >1 m below the base of the infiltration device			
Ground stability			
Confirm that it has been demonstrated that infiltration will not cause significant risk of instability (eg retaining walls, slopes, solution features or loosely consolidated fill) or movement that could adversely affect any nearby buildings or other structures. Where infiltration is proposed closer than 5 m to the foundations of buildings or structures that this assessment should be approved by a suitably qualified professional such as a registered ground engineering adviser. The BGS Infiltration SuDS Map is a useful source of information. Some local authorities have solifluction maps			
Confirm that an assessment has been taken of the potential for subsidence due to infiltration			
Ground contamination			
Confirm that an assessment of the potential for deterioration in groundwater quality due to infiltration, such as due to mobilisation of contamination, has been undertaken. Note: this assessment should be undertaken by a qualified geo-environmental engineer or similarly qualified person, and may require a site investigation with contamination testing. The BGS Infiltration SuDS Map can provide useful preliminary information			
Confirm that a suitable treatment train has been provided before the runoff reaches the soil (to reduce risks of groundwater contamination to an acceptable level) – see National SuDS Standards and this manual			
Flood risk			
Confirm that an assessment has been undertaken of the potential effect of infiltration on groundwater levels local to any infiltration component and the potential wider impact of multiple infiltration components within the site, with respect to groundwater flood risk			

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TABLE B.6 Infiltration assessment checklist

Infiltration capacity	Details	Acceptable submission?	Further requirements
Confirm that an assessment has been undertaken of the risk of springs developing in layered geology/steep topography due to the proposed infiltration			
Confirm that details of overflows or additional discharge points if total infiltration cannot be relied on for all return period events have been provided			
Combined sewer risk			
Confirm that an assessment has been undertaken of the risk of groundwater leakage into any local combined sewers			

B.5 SUDS COMPONENT DESIGN CHECKLISTS

B.5.1 Proprietary treatment systems

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 14**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

The checklist can be used for a single system or groups of systems with the same characteristics.

TABLE B.7 Design assessment checklist: proprietary treatment system

General information			
Site ID			
Asset ID(s)			
System location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary treatment processes provided:			
System description			

Check	Summary details	Acceptable (Y/N)	Comments/ remedial actions
Dimensions			
Dimension 1 (m) (describe)			
Dimension 2 (m) (describe)			
Dimension 3 (m) (describe)			
Depth to base – maximum and minimum (m)			
Cover – maximum and minimum (m)			
Inflows (Section 14.8.1)			
Provide a description of the contributing catchment land use and its size (m^2)			
Does the design include suitable inlet system to manage design inflows?			
Outflows (Section 14.8.2)			
Provide details of any flow control systems, overflow arrangements (for events that exceed the treatment event) and limiting discharge rate (s) from basin			
Maximum flow rate (and return period) for flows to be conveyed through the system			
Water quality performance (Section 14.5)			
Provide test data to show that the system delivers adequate removal of pollutants for rainfall events up to the 1 year return period. The critical type (duration) of event must be considered where the hydraulic behaviour is an essential component of the effectiveness of the treatment achieved			
Provide test data to show that the design minimises the risk of pollutants being remobilised and washed through the system by subsequent rainfall events, whether small or large			
Structural (Section 14.2)			
Confirm type of unit or structure to be used			
Confirm that calculations are provided to demonstrate acceptable structural capacity over the proposed system design life and approved by a chartered engineer			

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TABLE B.7 Design assessment checklist: proprietary treatment system

Check	Summary details	Acceptable (Y/N)	Comments/ remedial actions
Critical materials and product specifications (Section 14.9)			
Geomembrane			
Geotextile (non-woven)			
Topsoil			
Other (including proprietary systems)			
Constructability (Section 14.11)			
Are there any identifiable construction risks? If yes, state and confirm that acceptable risk management measures are proposed			
Maintainability (Section 14.12)			
Confirm that access for maintenance is acceptable and summarise details			
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required			
Confirm required maintenance frequency and cost of replacement filters etc			
Identify any custom items required for maintenance that may be difficult to obtain from other suppliers			

System design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

B.5.2 Filter strips

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process, and ensuring that designs meet the key design requirements set out in **Chapter 15**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

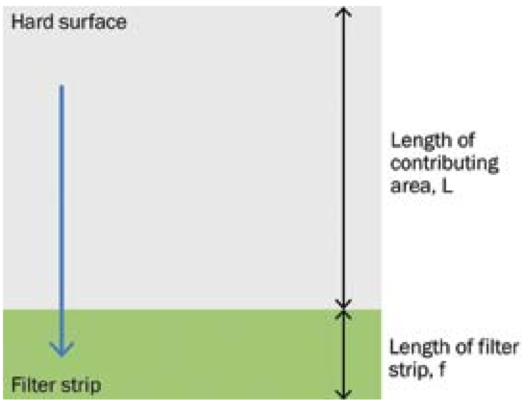
Minimum design requirements are provided in **Table B.8**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and/or performance have been managed appropriately.

The checklist can be used for a single filter strip or groups of filter strips with the same characteristics.

Clarification of filter strip dimensions is provided in **Figure B.1**.

TABLE B.8 Minimum design requirements: filter strip

Parameter	Minimum design requirements (MDRs)
Drop from adjacent surface onto filter strip	50–100 mm
Longitudinal slope	1 in 100 < Slope in direction of flow < 1 in 20
Maximum velocity across filter strip at full flow conditions	1.5 m/s
Maximum water depth at full flow conditions	100 mm
For the 1 year 30 minute: ▪ residence time ▪ flow height ▪ maximum velocity	 9 minutes 100 mm 0.3 m/s



Note

Filter strips are principally treatment systems although they can be used to convey flows from larger events.

Figure B.1 Filter strip dimensions (plan)

TABLE B.9 Design assessment checklist: filter strip

General information			
Site ID			
Asset ID(s)			
Filter strip location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function(s) of filter strip	Conveyance/treatment		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Section 15.2)				
Length of contributing drainage area (in direction of flow), L (m)	✓			
Length of filter strip (in direction of flow), f (m)	✓			
Width (m)				
Longitudinal slope (1 in ?)	✓			
Inflows (Section 15.8.1)				
Provide a description of the contributing catchment land use and its size (m^2)				
Does the design include: ▪ a suitable flow spreading device? ▪ appropriate drops from the adjacent surface into the filter strip?	✓			
Outfall arrangements (Section 15.8.2)				
Provide details of discharge arrangements from filter strip				
Is the filter strip designed to allow infiltration? If yes, attach the infiltration assessment				
Is a geomembrane required to prevent infiltration? If yes, give reason and reference specification or drawing				
Depth to maximum likely groundwater level (m)				
Conveyance (Section 15.4)				
Proposed vegetation, and assumed roughness criteria (Manning's "n")				
Maximum velocity across filter strip at full flow conditions (m/s)	✓			
Maximum water depth at full flow conditions (m)	✓			

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TABLE B.9 Design assessment checklist: filter strip

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Water quality treatment (Section 15.5)				
For the 1 year 30 minute event confirm: Flow height is acceptable for effective treatment Or Maximum velocity is acceptable for effective treatment	✓ ✓			
Critical materials and product specifications (Section 15.9)				
Geomembrane				
Geotextile (non-woven)				
Topsoil				
Other (including proprietary systems):				
Landscape/biodiversity (Sections 15.6, 15.7 and 15.10)				
Does the proposed planting have potential to create biodiverse habitats?				
Have native plant species been used? (Note if ornamental species are proposed, give reasons and describe measures that prevent their migration to natural water bodies.)				
Is the proposed planting appropriate to the location, visually, relative to gradient, water depths etc and with respect to access and maintenance?				
Where relevant, confirm planting design does not adversely impact highway visibility and safety requirements (check with highway authority)				
Is the proposed topsoil profile suitable to sustain the proposed plant species and is it sufficiently permeable?				
Constructability (Section 15.11)				
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed				
Maintainability (Section 15.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				

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TABLE B.9 Design assessment checklist: filter strip

Filter strip design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

B.5.3 Filter drains

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 16**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

Minimum design requirements are provided in **Table B.10**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and/or performance have been managed appropriately.

The checklist can be used for a single drain or groups of drains with the same characteristics.

TABLE B.10 Minimum design requirements: filter drain

Drain parameter	Minimum design requirements (MDRs)
Width	Width > 0.3 m
Depth	Depth > 1 m
Fill specification	HA (2009a) or equivalent

TABLE B.11 Design assessment checklist: filter drain

General information			
Site ID			
Asset ID(s)			
Drain location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function(s) of trench:	Conveyance/attenuation/infiltration/treatment		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Section 16.2)				
Length (m)				
Width (m)	✓			
Depth (m)	✓			
Longitudinal gradient (1 in ?)				
Dimensions of collector pipes (mm)				
Inflows (Section 16.8.1)				
Provide a description of the contributing catchment land use and its size (m^2)				
Does the design include suitable silt Interception before trench?				
Outfall arrangements (Section 16.8.2)				
Provide details of any flow control system, overflow arrangements and limiting discharge rate from trench				
Is the trench designed to allow infiltration? If yes, attach infiltration assessment				
Is a geomembrane required to prevent infiltration? If yes, give reason				
Depth to maximum likely groundwater level (m)				
Conveyance (Section 16.4)				
Proposed trench infill, permeability (m/s), void ratio (if used as storage system)	✓			
Confirm that trench capacity is adequate to convey the design flow, taking account of the infill permeability				
Maximum design flow rate (m^3/s) or storage capacity (m^3) and design event return period (years)				
Critical materials and product specifications (Section 16.9)				
Geomembrane				
Geotextile (non-woven)				

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TABLE B.11 Design assessment checklist: filter drain

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Topsoil				
Gravel fill				
Perforated pipework				
Other (including proprietary systems)				
Constructability (Section 16.11)				
Are there any identifiable construction risks? If yes, state risk and confirm acceptable risk management measures are proposed				
Maintainability (Section 16.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				
Drain design acceptability	**Summary details including any changes required**		**Acceptable (Y/N)**	**Date changes made**
Acceptable: Minor changes required: Major changes required/redesign:				

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

B.5.4 Swales

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 17**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

Minimum design requirements are provided in **Table B.12**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and/or performance have been managed appropriately.

The checklist can be used for a single swale or groups of swales with the same characteristics.

TABLE B.12 Minimum design requirements: swale

Parameter	Minimum design requirements (MDR's)
Drop from adjacent surface onto swale (for direct lateral inflows)	50–100 mm
Base width	0.5 m < base width < 2 m
Side slope	Side slope < 1 in 3
Longitudinal slope	Bed slope < 1 in 40
Maximum velocity in swale at full flow conditions	2 m/s
Maximum water depth at full flow conditions	600 mm
For the 1 year, 30 min event: ▪ average residence time in swale ▪ flow height ▪ maximum velocity	 > 10 minutes < 100 mm < 0.3 m/s
For infiltration/underdrained swales: permeability of topsoil	> permeability of underlying soils

TABLE B.13 Design assessment checklist: swale

General information			
Site ID			
Asset ID(s)			
Swale location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function(s) of swale	Conveyance/attenuation/infiltration/treatment/other dual use (specify)		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Section 17.2)				
Length (m)				
Width – at top and at base (m)	✓			
Side slopes (1 in ?)	✓			
Depth – maximum and minimum (m)				
Freeboard (m)				
Longitudinal slope (1 in ?)	✓			
Distance between check dams (if provided) (m)				
Dimensions of any underdrain (m)				
Dimensions of any perforated pipe within underdrain (mm)				

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TABLE B.13 Design assessment checklist: swale

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Inflows (Section 17.8.1)				
Provide a description of the contributing catchment land use and its size (m^2)				
Does the design include suitable silt Interception upstream of system, where required (usually if the system is designed to infiltrate runoff)?				
Does the design include: ▪ a suitable flow spreading device ▪ appropriate drops from the adjacent surface into the swale ▪ appropriate energy dissipation?	✓			
Outfall arrangements (Section 17.8.2)				
Provide details of any flow control systems, overflow arrangements and limiting discharge rate from swale				
Is the swale designed to allow infiltration? If yes, attach infiltration assessment				
Is a geomembrane required to prevent infiltration? If yes, give reason				
Depth to maximum likely groundwater level (m)				
Is topsoil sufficiently permeable to allow infiltration or underdrainage, if required?	✓			
Conveyance (Section 17.4)				
Proposed vegetation, and assumed roughness criteria (Manning's "n")?				
Maximum velocity in swale at full flow conditions	✓			
Maximum water depth at full flow conditions	✓			
Maximum flow rate (m^3/s) or stored volume (m^3) and design event return period (years)				
Water quality treatment (Section 17.5)				
For the 1 year 30 minute event confirm: Average residence time in swale is acceptable for effective treatment Or Flow height is acceptable for effective treatment Or Maximum velocity is acceptable for effective treatment	✓ ✓ ✓			

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TABLE B.13 Design assessment checklist: swale

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Landscape/biodiversity (Sections 17.6, 17.7 and 17.10)				
Does the swale planting include: ▪ grassed ▪ other native species ▪ other species or features?				
Provide a planting schedule showing species and planting preferences. Is the planting demonstrated to be appropriate for the habitat specified?				
Will plantings be established or rely on natural colonisation?				
Have locally appropriate native plant species been used?				
Indicate the number of different plant species used (not a monoculture)				
Is the proposed swale planting appropriate to the location, and with respect to access and maintenance?				
Where relevant, confirm that planting design does not adversely impact highway visibility and safety requirements (check with highway authority)				
Is the proposed topsoil profile suitable to sustain the proposed plant species?	✓			
Critical materials and product specifications (Section 17.9)				
Geomembrane				
Geotextile (non-woven)				
Topsoil				
Other (including underdrain material):				
Constructability (Section 17.11)				
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed				
Maintainability (Section 17.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				

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TABLE B.13 Design assessment checklist: swale

Swale design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

B.5.5 Bioretention systems

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 18**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

Minimum design requirements (MDRs) are provided in **Table B.14**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and/or performance have been managed appropriately.

The checklist can be used for a single bioretention systems or groups of similar features with the same characteristics.

Note: Bioretention systems are principally treatment systems and should not be used as a flow pathway for design flow events.

TABLE B.14 Minimum design requirements: bioretention systems

Parameter	Minimum design requirements (MDRs)
Surface area	Sufficient to store design treatment event at a depth of 150 mm on the surface
Flow through filter bed	Design treatment event should fully drain in 24–48 hours
Minimum depth of filter bed	1.0 m
Maximum longitudinal slope	1 in 20
Drop from adjacent surface onto bioretention system (for direct lateral inflows)	50–100 mm

TABLE B.15 Design assessment checklist: bioretention system

General information			
Site ID			
Asset ID(s)			
Bioretention system location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function of bioretention system	Treatment		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Section 18.2)				
Length (m)				
Width (m)				
Top surface area (m^2)				
Side slopes (1 in ?)				
Depth (m)				
Freeboard (m)				
Longitudinal slope (1 in ?)	✓			
Inflows (Section 18.8.1)				
Provide a description of the contributing catchment land use and its size (m^2)				
Does the design include: ▪ a suitable flow spreading device ▪ appropriate drops from the runoff surface into the bioretention system ▪ appropriate energy dissipation?	✓			
Outfall arrangements (Section 18.8.2)				
Provide details of any flow control systems, overflow arrangements (for events greater than the treatment capacity) and limiting discharge rate from bioretention system				

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TABLE B.15 Design assessment checklist: bioretention system

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Is the bioretention system designed to allow infiltration? If yes, attach infiltration assessment				
Is a geomembrane required to prevent infiltration? If yes, give reason				
Depth to maximum likely groundwater level (m)				
Water quality treatment (Section 18.5)				
For the 1 year 30 minute event or water quality treatment volume confirm:				
Maximum depth of surface ponding is 150 mm	✓			
Surface ponding is fully drained down in 40–48h	✓			
Depth of filter bed (m)	✓			
Storage (Section 18.4)				
Design return period(s) (years)				
Maximum design water depth(s) and level(s)				
Maximum design storage volume(s) (m^3)				
Landscape/biodiversity (Sections 18.6, 18.7 and 18.10)				
Does the proposed planting have potential to create biodiverse habitats?				
Have native plant species been used? (Note: if ornamental species are proposed, give reasons and describe measures that prevent their migration to natural water bodies)				
Is the proposed planting appropriate to the location, visually, relative to gradient, water depths etc and with respect to access and maintenance?				
Where relevant, confirm that planting design does not adversely impact highway visibility and safety requirements (check with highway authority)				
Is the proposed topsoil profile suitable to sustain the proposed plant species and as permeable as the filter bed?				
Critical materials and product specifications (Section 18.9)				
Geomembrane				
Geotextile (non-woven)				
Mulch layer				
Filter medium				
Transition layer				
Drainage layer				
Other (including proprietary systems):				

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TABLE B.15 Design assessment checklist: bioretention system

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Constructability (Section 18.11)				
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed				
Maintainability (Section 18.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				
Bioretention design acceptability	**Summary details including any changes required**		**Acceptable (Y/N)**	**Date changes made**
Acceptable: Minor changes required: Major changes required/redesign:				

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

B.5.6 Pervious pavements

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 20**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

The checklist can be used for a single pavements or groups of pavements with the same characteristics.

TABLE B.16 Design assessment checklist: pervious pavement

General information			
Site ID			
Asset ID(s)			
Pavement Location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function of pavement	Attenuation/infiltration/water quality		

Check	**Summary details**[1]	**Acceptable (Y/N)**	**Comments/ remedial actions**
Surfacing (Section 20.1 and 20.2)			
Type of surfacing (block paving, porous asphalt or plastic reinforced gravel/grass)			
Confirm surfacing is suitable for the location and will withstand likely forces (eg turning forces from HGVs)			
Confirm that all shallow services are located within service corridors beneath impermeable surface, as far as possible			
Permeability of surface layer			
Specified joint infill or grid infill			
Specified binder for porous asphalt (to ensure maximum adhesion to aggregate)			
Specified filler for porous asphalt (to ensure maximum adhesion to aggregate)			
Dimensions (Section 20.9)			
Length (m)			
Width (m)			
Depth of capping layer (m)			
Depth of sub-base (m)			
Depth of laying course or regulating layer (m)			
Maximum longitudinal or cross gradient (1 in ?)			
Distance between check dams in sub-base (if provided) (m)			
Inflows (Section 20.10.1)			
Provide a description of the contributing catchment land use (ie overlying surface only or additional inflows) and its size (m^2)			
Where the pavement accepts point source inflows, does the design include suitable energy diffusers?			
Outfall arrangements (Section 20.10.2)			
Is the pavement designed to allow infiltration into the subgrade? If yes, attach infiltration assessment			

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TABLE B.16 Design assessment checklist: pervious pavement

Check	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Provide details of any flow control systems, overflow arrangements and limiting discharge rate from pavement			
Is a geomembrane required to prevent infiltration or protect foundations? If yes, give reason			
Depth to maximum likely groundwater level (m)			
Attenuation (Section 20.5)			
Confirm voids ratio of sub-base material			
Demonstrate collection pipework is of sufficient capacity?			
Demonstrate that if the sub-base is used to convey water, the flow capacity will be sufficient?			
Provide calculations for maximum water depth and return period for the design event			
Check dams required because of sloping subgrade? If yes, provide details			
Structural pavement design (Section 20.9)			
CBR* used in design and confirm it is appropriate to the soils below the site when wetted			
Assumed traffic loads used in design			
Design method used for structural design and provide calculations			
Landscape (Sections 20.7 and 20.12)			
Is the proposed planting adjacent to the pavement appropriate to the location?			
Is pavement protected from silt wash off from adjacent planting areas?			
Critical materials and product specifications (Section 20.11)			
Geomembrane			
Geotextile (non-woven)			
Geogrids			
Blocks/asphalt/plastic grids			
Block jointing or grid infill material			
Laying course			
Base course (Note: where this is to be used as a temporary running course during construction, demonstrate that the puncture frequency is sufficient to support the design hydraulic performance of the system)			
Sub-base			
Capping layer			

continued...

continued from...

TABLE B.16 Design assessment checklist: pervious pavement

Check	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Topsoil			
Other (including proprietary systems)			
Constructability (Section 20.13)			
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed. (Note: key requirement to protect permeable surface during construction.)			
Maintainability (Section 20.14)			
Confirm that access for maintenance is acceptable and summarise details			
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required			

Pavement design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

Note

1 CBR = California bearing ratio. This is a penetration test for evaluation of the mechanical strength of subgrades and basecourses.

B.5.7 Attenuation storage tanks

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in Chapter 21. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

The checklist can be used for a single system or groups of systems with the same characteristics.

TABLE B.17 Design assessment checklist: attenuation storage tank

General information			
Site ID			
Asset ID(s)			
System location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
System description:			

Check	**Summary details**	**Acceptable (Y/N)**	**Comments/ remedial actions**
Dimensions (Section 21.4)			
Length (m)			
Width (m)			
Depth to base – maximum and minimum (m)			
Depth of cover over top of system – maximum and minimum (m)			
Longitudinal base slope (1 in ?)			
Inflows (Section 21.9.1)			
Provide a description of the contributing catchment land use and its size (m^2)			
Does the design include suitable silt Interception upstream of system?			
Does the design include suitable inlet and/or conveyance system to manage design flows – provide flow rate of water through side of crates, through perforated pipes or similar?			
Outfall arrangements (Section 21.9.2)			
Provide details of any flow control systems, overflow arrangements, drain-down time and limiting discharge rate from system			
Is the system designed to allow infiltration? If yes, attach infiltration assessment			
Is a geomembrane required to prevent infiltration? If yes, give reason			
Depth to maximum likely groundwater level (m)			
Storage (Section 21.5)			
Design return period(s) (years)			
Maximum design water depth(s) and level(s)			
Maximum design storage volume(s) (m^3) (include total system volume, void ratio and available volume)			
Structural (Section 21.4)			
Confirm type of unit or structure to be used			
Confirm assumed traffic or other design loadings used in design plus short-term and long-term performance			

continued...

continued from...

TABLE B.17 Design assessment checklist: attenuation storage tank

Check	Summary details	Acceptable (Y/N)	Comments/ remedial actions
Confirm that calculations are provided to demonstrate acceptable structural capacity over the proposed system design life that are approved by a chartered engineer			
Confirm that design and construction checklists, project roles and sign-off, designer evaluation form and product evaluation form in accordance with O'Brien *et al* (in press) have been provided			
Are there any unusual geotechnical risks? If yes, state and confirm acceptable risk management measures are proposed			
Has sufficient venting been provided to allow excess air pressure to be released when tank fills?			
Critical materials and product specifications (Section 21.9)			
Geomembrane			
Geotextile (non-woven)			
Topsoil			
Other (including proprietary systems):			
Constructability (Section 21.12)			
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed			
Maintainability (Section 21.13)			
Confirm that access for maintenance is acceptable and summarise details			
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required			

System design acceptability	Summary details including any changes required	Acceptable (Y/N)	Date changes made
Acceptable: Minor changes required: Major changes required/redesign:			

B.5.8 Infiltration and detention basins

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapters 13 and 22**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references for the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

Minimum design requirements (MDRs) are provided in **Table B.18**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and performance have been managed appropriately.

The checklist can be used for an infiltration/detention basin or groups of such basins with the same characteristics.

TABLE B.18 Minimum design requirements: basin

Basin Parameter	**Minimum design requirements (MDRs)**	
	Infiltration	**Detention**
Length:width ratio	N/A	> 2:1
Side slope	Side slope < 1 in 3	Side slope < 1 in 3
Longitudinal slope	Bed slope < 1 in 40	Bed slope < 1 in 40
Maximum water depth for 1 in 100 year event	1 m	1 m
Permeability of topsoil	> permeability of underlying soils	N/A
For the 1 year 30 minute event: ▪ average residence time in basin ▪ flow height ▪ velocity	N/A	 > 9 minutes <100 mm < 0.3 m/s

TABLE B.19 Design assessment checklist: basin

General information			
Site ID			
Asset ID(s)			
Basin location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function(s) of basin:	Attenuation/infiltration/treatment/other dual use (specify)		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Sections 13.2 and 22.2)				
Length (m)	✓			
Width – at top and at base (m)	✓			
Top surface area (m^2)				
Side slope (1 in ?)	✓			
Depth – maximum and minimum (m)				
Freeboard (m)				
Longitudinal slope (1 in ?)	✓			
Inflows (Sections 13.8.1 and 22.8.1)				
Provide a description of the contributing catchment land use and its size (m^2)				
Does the design include suitable silt Interception upstream of system, where required?				
Where required, does the design include: ▪ suitable flow spreading ▪ appropriate energy dissipation?				
Outfall arrangements (Sections 13.8.2 and 22.8.2)				
Provide details of any flow control systems, overflow arrangements and limiting discharge rate(s) from the basin				
Is the basin designed to allow infiltration? If yes, attach infiltration assessment				
Does the design include infiltration trenches or blankets beneath the base to promote improved infiltration?				
Is a geomembrane required to prevent infiltration? If yes, give reason				
Depth to maximum likely groundwater level (m)				
Is topsoil of sufficient permeability to allow infiltration or underdrainage (where required)?	✓			
Storage (Sections 13.4 and 22.4)				
Design return period(s) (years)				

continued...

continued from...

TABLE B.19 Design assessment checklist: basin

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Maximum design water depth(s) and level(s)	✓			
Maximum design storage volume(s) (m^3) Note: It would be unusual for this volume to exceed 10,000 m^3. If it does, the design may have to comply with the Reservoirs Act 1975 (as amended by the Flood and Water Management Act (FWMA) 2010). Checks should be made of the design to confirm suitability of such a large volume				
Levels around the edge of the pond/ wetland appropriate to contain design depths of water?				
Water quality treatment (Sections 13.5 and 22.5)				
For the 1 year, 30 min event confirm:				
Average residence time in detention basin is acceptable for effective treatment Or Maximum velocity is acceptable for effective treatment	✓ ✓			
Landscape/biodiversity (Sections 13.6, 13.7, 13.10, 22.6, 22.7 and 22.10)				
Does the proposed planting have potential to create biodiverse habitats?				
Have native plant species been used? (Note: if ornamental species are proposed, give reasons and describe measures that prevent their migration to natural water bodies.)				
Is the proposed planting appropriate to the location, visually, relative to gradient, water depths etc and with respect to access and maintenance?				
Where relevant, confirm planting design does not adversely impact highway visibility and safety requirements (check with highway authority)				
Is the proposed topsoil profile suitable to sustain the proposed plant species and as permeable as the filter bed?				
Critical materials and product specifications (Sections 13.9 and 22.9)				
Geomembrane				
Geotextile (non-woven)				
Topsoil				
Other (including proprietary systems)				

continued...

continued from...

TABLE B.19 Design assessment checklist: basin

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Constructability (Sections 13.11 and 22.11)				
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed				
Maintainability (Sections 13.12 and 22.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				
Basin design acceptability	**Summary details including any changes required**		**Acceptable (Y/N)**	**Date changes made**
Acceptable: Minor changes required: Major changes required/redesign:				

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

B.5.9 Ponds and wetlands

This checklist can be used by the organisation approving the drainage scheme (drainage approving body) to help assess submissions for drainage approval.

This checklist is aimed at providing a consistent assessment process and ensuring that designs meet the key design requirements set out in **Chapter 23**. The design guidance in the manual provides details that support the implementation of this checklist so that designs and compliance assessment can be delivered effectively. Appropriate section references from the manual are provided in the checklist.

This checklist should form part of a suite of documents required for a submission for drainage approval, including (but not limited to):

- a scheme design assessment
- detailed infiltration assessment (where infiltration components are proposed)
- a scheme health and safety risk assessment (if required)
- a scheme construction method statement
- a scheme Maintenance Plan.

It can be used as a checklist by organisations responsible for the approval and adoption of SuDS to support their assessment of schemes, or it can be used as part of the required submissions from the developer. It can also help designers ensure that they have provided all relevant information to the drainage approving body in their submissions for approval.

Minimum design requirements are provided in **Table B.20**. Where there are variations from these, justification should be provided and evidence set out that risks relating to safety and/or performance have been managed appropriately.

The checklist can be used for a single pond/wetlands or groups of similar features with the same characteristics.

TABLE B.20 Minimum design requirements: ponds/wetlands

Parameter	Minimum design requirements (MDRs)
Length to width ratio	> 3:1
Maximum depth of permanent water	2 m
Maximum side slopes	1 in 3
Maximum depth of aquatic bench below permanent water level	400 mm
Size of permanent pool	≥ treatment volume, V_t

TABLE B.21 Design assessment checklist: pond/wetland

General information			
Site ID			
Asset ID(s)			
Pond/wetland location(s) and co-ordinates		Drawing reference(s)	
Date of assessment		Specification reference(s)	
Primary function(s) of pond/wetland	Attenuation/treatment		

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Dimensions (Section 23.2)				
Length (m)				
Maximum and minimum width – at permanent water level (m)				
Length: maximum width ratio	✓			
Top surface area (m^2)				
Side slopes (1 in ?)	✓			
Depth of permanent water – maximum and minimum (m)	✓			
Freeboard (m)				
Aquatic bench width and slope (m, 1 in ?)	✓			
Safety bench width and slope (m, 1 in ?)	✓			
Inflows (Section 23.8.1)				
Provide a description of the contributing catchment land use and its size (m2)				
Does the design include suitable silt Interception upstream of system?				
Does the design include: ▪ a suitable inlet design ▪ appropriate energy dissipation?				
Outfall arrangements (Section 23.8.2)				
Provide details of any flow control systems, overflow arrangements and limiting discharge rate from pond/wetland				

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TABLE B.21 Design assessment checklist: pond/wetland

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Is a geomembrane required to prevent infiltration? If yes, give reason				
Depth to maximum likely groundwater level (m)				
Storage (Section 23.4)				
Design event return period(s) (years)				
Maximum rise in water level(s) for the design event(s) (mm)	✓			
Maximum water depth(s) at design event conditions (m)				
Maximum design storage volume(s) (m^3)				
Levels around the edge of the pond/ wetland appropriate to contain design depths of water?				
Water quality treatment (Section 23.5)				
For the 1 year, 30 min event confirm:				
Permanent pool volume is sufficient for effective treatment Or Flow velocity is acceptable for effective treatment	✓ ✓			
Landscape/biodiversity (Sections 23.6, 23.7 and 23.10)				
Is there sufficient treatment upstream of the pond to allow design amenity and biodiversity objectives to be delivered?				
Does the variation in permanent water depth have the potential to create biodiverse habitats?				
Does the design of the pond fulfil objectives of availability of different habitats including: ▪ deep water ▪ marginal ▪ dry/damp ▪ other				
A planting schedule is provided, showing species and planting preferences. Is the planting demonstrated appropriate for the habitat specified?				
Will plantings be established or rely on natural colonisation?				
Have locally appropriate native plant species been used?				
Indicate the number of different plant species used (not a monoculture)				

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TABLE B.21 Design assessment checklist: pond/wetland

Check	MDR	Summary details[1]	Acceptable (Y/N)	Comments/ remedial actions
Is the proposed pond/wetland planting appropriate to the location, and with respect to access and maintenance?				
Where relevant, confirm planting design does not adversely impact highway visibility and safety requirements (check with highway authority)				
Is the proposed topsoil profile suitable to sustain the proposed plant species?				
Critical materials and product specifications (Section 23.9)				
Geomembrane				
Geotextile (non-woven)				
Topsoil				
Other (including proprietary systems)				
Constructability (Section 23.11)				
Are there any identifiable construction risks? If yes, state and confirm acceptable risk management measures are proposed				
Maintainability (Section 23.12)				
Confirm that access for maintenance is acceptable and summarise details				
Are there specific features that are likely to pose maintenance difficulties? If yes, identify mitigation measures required				
Pond/wetland design acceptability	**Summary details including any changes required**		**Acceptable (Y/N)**	**Date changes made**
Acceptable: Minor changes required: Major changes required/redesign:				

Note

1 If there is an MDR (as indicated) confirm whether or not this is met and provide details of any variations.

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B.6 CONSTRUCTION METHOD STATEMENTS AND ASSESSMENT CHECKLISTS

B.6.1 Guidance on construction method statements

Why is a construction method statement such an important part of the drainage submission process?

The purpose of a construction method statement is to:

- formalise who is responsible for completing the work
- set out the approach, processes and programme proposed for constructing and stabilising the SuDS (so that those with delivery responsibility understand what is to be done, how and why)
- identify any unusual items or methods of working that are required.

Contractors and developers are familiar with preparing construction method statements for a wide variety of purposes, not least to manage health and safety and contractual risks on construction sites.

In terms of health and safety, the method statement should detail a safe system of work. It should identify the hazards that may arise during construction and the measures that should be taken to ensure that the hazards do not pose an unacceptable risk to workers and the public.

Method statements for SuDS are necessary because many people in the construction industry are not familiar with the specific requirements for constructing SuDS, and some of the requirements are contrary to accepted practice in some fields (for example, the requirement for a drop from hard surfaces to grassed areas where water is flowing off an edge is the opposite to normal landscape practice, which is to raise the turf level above the hard surface).

It is also important to understand the impact of other construction activities on the SuDS (for example, once permeable sub-base is laid, it cannot be used as a construction route or platform unless it is protected from siltation and loading damage).

The construction method statement can be used by the drainage adoption body to assess the constructability of the proposed design, to evaluate the construction implications and to plan the appropriate construction inspection regime that will enable an assessment that the system has been constructed in accordance with the design.

What needs to be included?

Every job is different and every method statement should be site specific. Most of the information included in standard method statements for health and safety and general management of the construction process will be acceptable, with the addition of information specific to the SuDS. This means that there will be negligible extra work required to prepare the SuDS construction method statement.

The main requirements for a construction method statement are:

- details of the nature of the work to be completed
- site plans and full scheme drawings, where these are required to support the method of approach
- consents and reinstatement requirements
- access points and details
- any site-specific ecological issues or features that require protection and/or consideration
- any likely water quality issues resulting from the SuDS construction
- the proposed strategy for sediment control and site drainage during the construction of the development, where this impacts on the SuDS proposed for the site; it should identify any potential impacts on the final performance of the drainage system and any necessary protection measures (or remedial works such as silt removal at the end of construction of the development)

- a detailed programme for construction of the drainage works (including stabilisation and planting of exposed surfaces); the programme should highlight key points at which inspection is recommended
- specific details where the proposed construction processes are unusual, unique or required by a specific product manufacturer
- what plant is required and how it will be used
- simple illustrations, where necessary, to aid understanding of what is required
- full contact information for:
  - site manager
  - the name of the person on site (usually a foreman) who will be responsible for the work
  - other relevant professional contacts, eg archaeologist, ecologist, drainage approving body, environmental regulator
  - emergency contact details.

The contractor or developer should provide the method statement to the drainage approving body before starting the drainage construction, and the statement should be discussed and agreed with the contractor at a pre-contract meeting. The information in the method statement should be communicated to site staff via a toolbox talk – which would routinely be required as part of the health and safety requirements for a site.

There may be a general high-level method statement that deals with, for example, phasing of different parts of the SuDS. Several more detailed statements that relate to specific work items may also be provided. Generic method statements should be avoided; they should be written for the site in question.

Where to find more information?

Detailed information on the requirements for SuDS construction and method statements is provided in **Chapter 31** and in Woods Ballard *et al* (2007).

Also, there are numerous method statements on the internet, and the best approach is to read a few of those to gain an idea of what information is provided, then apply that knowledge to the SuDS method statement for the particular site.

B.6.2 Construction inspection and assessment

Objectives

The objective of a construction assessment is to verify that the drainage system is constructed in accordance with the approved design and specification. Verification can be undertaken by the drainage approving body, by independent consultants employed by the drainage approving body or developer, or a combination of these. If the verification visits and report are undertaken by a consultant employed by the developer, there should be a contractual link to the drainage approving body via a warranty from the consultant, or some other mechanism.

Conflicts of interest should be avoided in the verification process. A contractor, supplier (eg permeable pavements) or developer certifying their own work or product is considered to be a conflict of interest and is not good practice. Verification also requires a full understanding of the drainage system for the site, how it fits in with the overall flood risk strategy and the philosophy underpinning the design. A contractor employed to install drainage or a supplier of materials or components is not likely to have this level of understanding of the site. Self-certification of construction is not acceptable.

It is intended that the suggested checklist provided here gives a broad outline of the items that will require checking. The precise details will vary from scheme to scheme, and the list should be adapted to suit each site. This will require the removal or addition of items as necessary.

Programme and method of approach

Work should not start on site until the drainage approving body has formally approved the drainage design plans, method statement and specification in writing. Further to this approval being given, the drainage approving body should then be given at least two weeks' notice of the proposed start of construction of the development and for larger sites should be provided with a programme of works. For smaller sites 48 hours' notice of any works requiring inspection should be sufficient. The drainage approving body should be notified immediately, and with sufficient notice, of any significant changes to the programme. This is to allow the drainage approving body sufficient opportunity to inspect the works.

The construction method statement should detail the specific SuDS construction methods and processes, and the construction programme, including key points at which inspection is recommended (eg when subsequent coverage of elements would mean inspection could not then be undertaken without removal of material).

Changes to design during construction

It is inevitable that there will be changes to the design during construction. This is a normal part of construction. However, it is important that changes are not made without reference to the drainage approving body/owner and/or the designer. Major changes should be agreed with both the approving body and the designer before implementing them (major changes are things that can have a significant impact on the overall operation and maintenance of the SuDS, eg changing a pond to a basin). Minor changes should be agreed with the designer, and the changes and agreement recorded for inclusion in the verification report (see below).

Verification report

A verification report should be prepared at the end of construction by the party who has carried out the inspection visits. This should confirm if the drainage system has been constructed in accordance with the approved design. It should identify any changes that have been made to the design and the reasons for those changes, together with confirmation of any likely impact on the performance of the system (if an adverse impact is expected then necessary remedial works should be specified). Evidence of the agreement of the drainage approving body and/or designer to the changes should be included.

The verification visit reports should indicate any defects in construction and follow up on any remedial works that are necessary to confirm that they have been completed.

The format of the report will be site specific, but as a minimum it will be expected to include the following:

- photographs of excavations, confirmation of soil conditions, confirmation of levels, profiles and General earthworks
- photographs and full manufacturers' details (if appropriate) of inlets, outlets and any control structures associated with any feature to be adopted
- confirmation of topsoil sources with appropriate certificates
- full planting lists and confirmation of plant sources, planting method statement and initial maintenance regime
- confirmation of subsoil and topsoil depths
- confirmation of gravel fill/sub-base specification and sources, installation method statement of filter drains/permeable pavements
- confirmation of source and test certificates for membrane liners if used (Membranes shall have welded joints and shall be inspected and the joints tested after installation. Records of the tests shall be provided. Integrity tests may be necessary if the membrane performance is critical.)
- photographs of the feature before and after planting
- full as-constructed drawings and a topographical survey of the as-constructed system
- confirmation of initial maintenance regimes.

TABLE B.22 Construction assessment checklist

General information			
Site ID			
Asset ID(s) (note the checklist can be used for a single component or a complete system)			
Site location(s) and co-ordinates		Drawing reference(s)	
Contractor/developer		Specification reference(s)	
Inspection dates			
Items/parts of system inspected			

Check	Details	Y	N	Details	Y	N	Details	Y	N
General									
Appropriate erosion and sediment control strategy implemented (including protection of any infiltration or permeable surfaces, permeable sub-base and stabilisation following earthworks)?									
Location, layout and plan area as per approved drawings?									
Critical root zones of nominated trees protected?									
Any identified ecological features adequately protected?									
Earthworks									
Levels and gradients as per approved drawings?									
Side slopes and benches as per approved drawings?									
Provision of subsoil drainage as per approved drawings?									
Topsoil depths as per approved drawings?									
Formation levels as per approved drawings									
Formation level soils as per design assumptions (eg CBR value)?									
Side slopes of temporary excavations for tanks as per approved drawings?									
Utilities access covers and street furniture details acceptable? (eg correct detailing of block paving around covers, not impeding flow in swales etc)									
Hydraulic properties									
Water levels as per approved drawings?									

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TABLE B.22 Construction assessment checklist

Check	Details	Y	N	Details	Y	N	Details	Y	N
Flow controls as per approved design?									
Structural components									
Check dams/weirs/overflows as per design?									
Service or other crossings as per design?									
Pipe connections as per design?									
Inlets – as per design, appropriate installation (including concrete and reinforcement works, erosion protection, level spreaders, buffer strips, kerbing and drops)									
Outlets – as per design, appropriate installation (including concrete and reinforcement works, erosion protection)									
Any required geotextile/geomembrane test certificates provided and in accordance with approved drawings and/or specification?									
Materials									
Topsoil meets approved specification (tested and ameliorated if required, certificates verifying source and content)?									
Planting implemented as per approved drawings and landscape schedules?									
Geocellular storage units as per approved design drawings and specification?									
Permeable sub-base as per approved drawings and specification?									
Root zone materials, filter sand etc as per approved drawing and specification?									
Perforated pipes as per approved drawings and specification?									
Final inspection									
Confirm inlet and outlet levels									
Confirm structural components									
Confirm slopes									
Confirm correct planting/turfing established									
Confirm no uneven settling of soil, channelling, unwanted ponding or erosion of bed or side slopes									
Confirm no evidence of construction sediment or unexpectedly rapid build-up of sediment									

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TABLE B.22 Construction assessment checklist

Check	Details	Y	N	Details	Y	N	Details	Y	N
Confirm that agreed access for maintenance is clear									
Further information appended									
Photographs									
Test certificates									
Other (details)									

B.7 CONSTRUCTION SPECIFICATION

The common construction specifications are:

- Civil Engineering Specification for the Water Industry (CESWI) (WRc, 2011)
- National Building Specification (NBS)
- Specification for Highway Works (SHW) (HA, 2005)

None of these currently include specific clauses for SuDS construction. However, they do contain clauses for most of the common construction activities and materials used in SuDS, or provision for including them.

The different items will be found in different parts of each of the standard specifications, but this is not unusual for any item of construction (eg a car park surface and associated drainage would call upon HA (2009b, 2009c, 2009d).

Table B.23 summarises some of the features of the different specifications.

TABLE B.23 Construction specification examples and suitability for SuDS

Specification	Comments
CEWSI (WRc, 20110	Not freely available Commonly used by water engineers Not commonly used by landscape professionals Robust specification for earthworks and pavement materials Generic specifications rather than specific products
NBS	Refers to SHW for a lot of earthworks materials and aggregates Not very robust for earthworks or some other drainage items Not freely available Commonly used by architects and landscape architects Tends to rely on stating a particular product (ie not performance based)
SHW (HA, 2005)	Freely available Well established and understood by highways authorities and many developers and engineers Not commonly used by landscape professionals Robust specification for earthworks and pavement materials Generic specifications rather than specific products

An example specification is provided in Box B.1. This is for a site-specific SuDS and should not be used as it stands. It is an illustration of the wording, content and style that is likely to be suitable. Clauses should be developed for each element of each component and for all the main processes involved in the construction.

BOX B.1 **An example SuDS specification**

The example specification that follows is for a site-specific SuDS and should not be used as it stands. It is an illustration of the wording, content and style that is likely to be suitable. Clauses should be developed for each element of each component and for all the main processes involved in the construction.

Base specification

The base specification shall be HA (2005), supplemented by the following requirements.

General clauses

Erosion protection

The contractor is responsible for preventing erosion of the sustainable drainage system until all the vegetation within it is fully established. This is to be achieved by protecting the side slopes and base of swales, wetlands and other areas where water flows, with fully biodegradable matting.

If erosion occurs in any part of the systems the contractor shall repair these areas to the satisfaction of the client.

Planting

Limitations on planting

Planting is to be carried out between April and September. Seeding and turfing is to be undertaken in spring or autumn in suitable weather conditions. The contractor shall obtain the approval of the client to undertake planting, seeding or turfing.

Plant stock should be sourced from approved nurseries that only grow native species of local provenance, to avoid the introduction of alien species.

Topsoil is not to be placed within 300 mm of the permanent water level in the wetland. Wetland plants are to be directly planted into the subsoil.

Fertilisers and pesticides are not to be used.

Swale planting

The following planting mix shall be provided in the swale:

- 10% – *Iris pseudacorus* (water iris)
- 10% – *Carex riparia* (great pond sedge)
- 10% – *Carex nigra* (common sedge)
- 10% – *Carex acutiformis* (lesser pond sedge)
- 50% – *Sparganium erectum* (branched bur-reed)
- 10% – *Typha angustifolia* (lesser reed mace)

In the grassguard system, the topsoil shall be carefully hand rammed into the voids leaving a 25 mm space at the top. The seeds shall be mixed with the topsoil, placed in the 25 mm void and lightly compacted.

The edges of the swales should be seeded with a normal amenity grass mix with a wildflower component.

Wetland planting

The following planting mix shall be provided in the forebay area:

- 10% – *Iris pseudacorus* (water iris)
- 10% – *Carex riparia* (great pond sedge)
- 10% – *Carex nigra* (common sedge)
- 10% – *Carex acutiformis* (lesser pond sedge)

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BOX B.1 **An example SuDS specification**

- 50% – *Sparganium erectum* (branched bur-reed)
- 10% – *Typha angustifolia* (lesser reed mace)

The following planting shall be provided in the wetland and areas:

- 10% – *Agrostis stolonifera* (creeping bent grass)
- 10% – *Apium nodiflorum* (fools water cress)
- 20% – *Filipendula vulgaris* (meadowsweet)
- 10% – *Glyceria fluitans* (floating sweet grass)
- 10% – *Myosotis scorpioides* (water forget-me-not)
- 10% – *Mentha aquatica* (water mint)
- 10% – *Nasturtium officinale* (watercress)
- 10% – *Persicaria amphibian* (amphibious bistort)
- 10% – *Veronica beccabunga* (brooklime)

The wetland plants are to be planted at a density of 5 plants per m^2.

The edges of the forebay and wetland should be seeded with a normal amenity grass mix with a wildflower component.

Membranes for lining

The membrane for lining the wetland and swale shall meet the following requirements:

Type:	Cold-applied single layer robust welded flexible membrane suitable for waterproofing to structures and for water containment	
Property	**Value**	**Test method**
Thickness mm ±10%	1.0	ASTM D751-06 (2011)
Density g/cm³ min	0.9	ASTM D792-13
Tensile stress @ break min N/mm²	18	ASTM D638-14
Elongation @ break %	> 700	ASTM D638-14
Puncture resistance Min N	150	FTMS 101C (method 2065)
Tear resistance Min N	60	ASTM D1004-13
Dimensional stability % change max	±2.0	ASTM D1204-14 1 hr @ 100°C
Stress crack resistance	100%	ASTM 5397-07 (2012)
Volatile loss 5% Loss max	0.2	ASTM D1203-10 Method A
Ozone resistance	No cracks	ASTM D1149-07 (2012)
Carbon black contents	2–3%	ASTM 1603-14
Moisture vapour g/m²/day	< 0.1	ASTM E96/E96M-15
Methane permeability	0.11 g/m²/day/atm	European standard
Methane transmission rate	1.8×10^{-9} m³/m²/s/atm	BRE
Permeability coefficient	1.8×10^{-12}	

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BOX B.1 An example SuDS specification

Application temperature of the membrane shall be greater than 4°C.

Primer not required.

Number of layers : One (1).

Laps – minimum 120 mm.

Jointing: Shall be generally formed using twin seam fusion welding in accordance with manufacturers recommendations.

Extrusion welding shall be accepted only in areas where twin seam welding is inappropriate.

General workmanship

Prelaying checks: surface acceptability

- Before laying check that substrate surfaces are:
  - structurally sound
  - free from ridges and undulations
  - surface dry
  - cleaned of loose and extraneous material.

Construction acceptability:

- Before laying check that construction allows membrane continuity to be maintained.

Laying membrane:

- Membrane to be installed by qualified operatives recommended by membrane manufacturer and/or prefabricated into panels where appropriate to suit site requirements.
- Laid strictly in accordance with manufacturers' recommendations.
- Apply membrane firmly to substrate ensuring that trapped air is removed as application proceeds.
- Overlap and bond consecutive sheets as specified using recommended twin wedge hot air jointing methods to ensure full bonding at laps.
- When temperature is 4°C and falling, a hot air pre-heat system of welding shall be adopted.

Protection generally:

- Protect finished sheeting adequately where necessary to prevent puncturing during following works.
- Cover sheeting with permanent overlying construction as soon as possible.
- Immediately before covering, check for damage and repair as necessary.

Penetrations:

- All penetrations through the membrane shall be sealed with proprietary water resistant preformed cloaks.
- The cloaks shall be compatible with the membrane and approved by the engineer.

Geotextiles

Protection of membranes.

The geotextiles to be used in the system to protect liners and act as filters shall meet the following requirements:

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BOX B.1 **An example SuDS specification**

Type:	**Heavy-duty geotextile fleece** **Non-woven, needle-punched polypropylene**		
Typical physical properties shall be:			
Property	**Test method**	**Unit**	**Value**
Mass per unit area	BS EN 965:1995	g/m^2	300
Thickness under load 2 kPa	BS EN 964-1:1995	mm	3.8
CBR puncture resistance	BS EN ISO 12236:2006	kN	2000
CBR displacement	BS EN ISO 12236:2006	mm	81
Tensile strength (min) at max. load m.d	BS EN ISO 10319:2015	kN/m	9
Tensile extension (max) at max. load m.d	BS EN ISO 10319:2015	%	180
Water transmissivity at 100 mm head(min)	BS EN ISO 10319:2015	l/sq.m/s	135
Breakthrough head	BS EN ISO 10319:2015	mm	nil
Coefficient of permeability	BS EN ISO 10319:2015	m/s	5×10^{-3}
Apparent opening size 90% finer	BS EN ISO 10319:2015	microns	90–300

Laying generally:

- Filter/protection geotext23ile shall be laid continuously as detailed in the contract drawings.
- Overlaps shall be a minimum of 300 mm.

Filtration

Type 4/20 material for use in swale underdrains.

Material to BS EN 13242:2002+A1:2007.

Material to comprise crushed carboniferous limestone rock or concrete.

Properties	**Category to BS EN 13242:2002+A1:2007**
Grading	4/20, Gc 85–15, GTc 20/17.5
Fines content	f4
Shape	FI20
Resistance to fragmentation	LA30
Durability: ▪ water absorption to BS EN 1097-6:2000, Clause 7 ▪ for WA > 2%, magnesium sulphate soundness	 WA242 MS18
Resistance to wear	MDE20
Acid-soluble sulphate content:	AS0.2
Total sulphur	≤ 1% by mass
Leaching of contaminants	Crushed concrete should meet the requirements set out in EA (2010) for inert waste when tested in accordance with BS EN 12457-3:2002

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BOX B.1 **An example SuDS specification**

Type 2/6.3 material.

Material to BS EN 13242:2002+A1:2007.

Material to comprise crushed carboniferous limestone rock or concrete.

Properties	**Category to BS EN 13242**
Grading	Grading 2/6.3, Gc 80
Fines content	f4
Shape	FI20
Resistance to fragmentation	LA30
Durability: ▪ water absorption to BS EN 1097-6:2013, Clause 7 ▪ for WA > 2%, magnesium sulphate soundness	 WA242 MS18
Resistance to wear	MDE20
Acid-soluble sulphate content	AS0.2
Total sulphur	≤ 1% by mass
Leaching of contaminants	Crushed concrete should meet the requirements set out in EA (2010) for inert waste when tested in accordance with BS EN 12457-3:2002

Root zone mix for swale

The rootzone mix shall comprise a 70/30 mix of sand/topsoil.

The topsoil shall meet the requirements of BS 3882:1994.

Sand shall meet the following requirements:

Grading:

Sieve size (mm)	**% passing**
5.00	89–100
2.36	65–100
0.3	5–50
0.063	< 4

Saturated hydraulic conductivity – > 220 mm/h.

Total porosity – > 30% v/v.

pH – 6.5–8.5.

Grass reinforcement system to swale sides

Grid to comply with the general manufacturing and testing requirements of BS 6717:2001.

Soil to wetland base

The soil placed on the base and sides of the wetland shall be topsoil in accordance with Clause Q28/340.

Topsoil shall be compacted to remove large voids and produce a coherent mass while preventing over-compaction.

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BOX B.1 An example SuDS specification

Tolerances

The sides slopes of the swale should have a longitudinal and transverse tolerance of 10 mm in 3 m to promote sheet flow from the drained surface down the slope to prevent erosion occurring.

Contractor design elements

The wet well pumping station at end of swale is to be designed by the contractor in accordance with WRc (2011) including chamber, inlet and outlet, pumps and controls. The pumps provided are to provide a capacity of at least 94 l/s with a duty and standby pump provided.

Provision is to be made in the pumping station to add lime dosing equipment at a later date if required.

The wet well should be designed so that it traps and prevents floating debris (sawdust and woodchip) from entering the pumps and a means of removing the debris provided.

B.8 MAINTENANCE PLAN AND CHECKLIST

B.8.1 Why is a Maintenance Plan needed?

The purpose of a Maintenance Plan is to ensure that all those involved in the maintenance and operation of the SuDS system understand its functionality and maintenance requirements in terms of supporting long-term performance to the design criteria to which it was designed.

A Maintenance Plan delivered as part of a drainage submission:

- confirms that the designer has taken maintenance into account within the design
- demonstrates the competence of the designer
- provides a guide to the adoption team as to what the maintenance requirements of the system are and how they can be met most efficiently
- provides a basis for costing long-term maintenance budgets (and commuted sums, if required)
- provides a working document for use on site
- details procedures for dealing with emergency spillages, vandalism etc; it should include the local environmental regulator telephone number, which should be called in case of spillages or other pollution incidents.

The Maintenance Plan for the drainage system should be designed in co-operation with the adopting organisation, and the information therein should be presented and discussed verbally with all those involved in inspecting and maintaining the drainage systems.

B.8.2 What should a Maintenance Plan include?

The SuDS Maintenance Plan should cover and clarify the following issues:

- a description of the site – concentrating on describing how the drainage system works in practice and what it is trying to achieve. This is likely to include flow routes, sub-catchments, SuDS components, flow control features and outfall arrangements. It should also explain the visual and biodiversity aspects of a scheme, as these can easily be compromised by inappropriate maintenance.
- a plan of the site that identifies runoff sub-catchments, SuDS components, critical water levels, control structures, flow routes (including exceedance routing) and outfalls

- a plan clearly showing the extent of the adopted area along with easements and rights of way for access to carry out maintenance. If other parties are responsible for different parts of a scheme, this should be clearly shown on the plan.
- the access that is required to each surface water management component for maintenance purposes and a plan for the safe and sustainable removal and disposal of waste periodically arising from the drainage system
- a review of the work to be undertaken, based on regular day-to-day maintenance, occasional tasks and remedial work. Details of the likely maintenance requirements for each SuDS element are provided in this Manual. Maintenance requirements for proprietary systems should be provided by the manufacturer or supplier.
- the maintenance specification – detailing the materials to be used and the standard of work required. A specification should describe how the work should be carried out and should contain clauses giving general instructions to the maintenance contractor.
- the maintenance schedule of work – itemising the tasks to be undertaken and the frequency at which they should be performed so that an acceptable long-term performance standard is secured. This schedule can then be priced and checked on site, and it can form the basis of an inspection log where appropriate. The schedule should be a living document because it may change, where inspections advise changes to the scheme maintenance requirements.
- contact sheet and any extra guidance notes – eg action plan for dealing with accidental spillages
- photographic records of the inspections. This can pick up long-term changes that might not be apparent on a single visit, especially where inspections are carried out by different members of staff.

Note: An example of a Maintenance Plan is available in Box B.2.

B.8.3 Maintenance inspection checklist

This checklist is a generic list that can be added to, or have items removed from it, to suit a particular site. The exact content of the checklist will depend on the combination of different SuDS components used in a scheme. Checklists should be selected based on the combination of elements in the drainage system to provide a bespoke inspection report.

The objective of this checklist is to:

- confirm that appropriate routine maintenance of the system is being undertaken
- confirm that the system is continuing to operate effectively
- identify any remedial works required
- provide a consistent record of the condition and performance of the system.

It is not a checklist of maintenance items, which is covered in **Chapters 11 to 23** of this manual (**Table B.24**). It is a checklist to facilitate consistent inspection of the condition of the system. It can be used by any organisation responsible for the long-term maintenance of the SuDS system as a recording process, or by a subcontracted organisation as part of their client reporting procedures.

Inspections should comply with all relevant health and safety legislation (The Management of Health and Safety at Work Regulations 1999) including the development of risk assessments for working close to or in water.

Inspections should ideally be carried out monthly (and no less than three-monthly), at the same time as other routine maintenance activities.

TABLE B.24 Where to find information on maintenance activities and frequencies

Component	Ref (within this Manual)
Green roofs	Section 12.12
Infiltration systems	Section 13.12
Proprietary systems	Section 14.12
Filter strips	Section 15.12
Filter drains	Section 16.12
Swales	Section 17.12
Bioretention systems	Section 18.12
Trees	Section 19.12
Pervious pavements	Section 20.14
Attenuation storage tanks	Section 21.13
Detention basins	Section 22.12
Ponds and wetlands	Section 23.12

TABLE B.25 SuDS maintenance inspection checklist

General information			
Site ID			
Site location and co-ordinates (GIS if appropriate)			
Elements forming the SuDS scheme		Approved drawing reference(s)	
Inspection frequency		Approved specification reference	
Type of development		Specific purpose of any parts of the scheme (eg biodiversity, wildlife and visual aspects)	

Inspection date								
	Details	**Y/N**	**Action required**	**Date completed**	**Details**	**Y/N**	**Action required**	**Date Completed**
General inspection items								
Is there any evidence of erosion, channelling, ponding (where not desirable) or other poor hydraulic performance?								
Is there any evidence of accidental spillages, oils, poor water quality, odours or nuisance insects?								
Have any health and safety risks been identified to either the public or maintenance operatives?								
Is there any deterioration in the surface of permeable or porous surfaces (eg rutting, spreading of blocks or signs of ponding water)?								
Silt/sediment accumulation								
Is there any sediment accumulation at inlets (or other defined accumulation zones such as the surface of filter drains or infiltration basins and within proprietary devices)? If yes, state depth (mm) and extent. Is removal required? If yes, state waste disposal requirements and confirm that all waste management requirements have been complied with (consult environmental regulator)								

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TABLE B.25 SuDS maintenance inspection checklist

Inspection date								
	Details	**Y/N**	**Action required**	**Date completed**	**Details**	**Y/N**	**Action required**	**Date Completed**
Is surface clogging visible (potentially problematic where water has to soak into the underlying construction or ground (eg underdrained swale or infiltration basin)?								
Does permeable or porous surfacing require sweeping to remove silt?								
System blockages and litter build-up								
Is there evidence of litter accumulation in the system? If yes, is this a blockage risk?								
Is there any evidence of any other clogging or blockage of outlets or drainage paths?								
Vegetation								
Is the vegetation condition satisfactory (density, weed growth, coverage etc)? (Check against approved planting regime.)								
Does any part of the system require weeding, pruning or mowing? (Check against maintenance frequency stated in approved design.)								
Is there any evidence of invasive species becoming established? If yes, state action required								
Infrastructure								
Are any check dams or weirs in good condition?								
Is there evidence of any accidental damage to the system (eg wheel ruts?)								
Is there any evidence of cross connections or other unauthorised inflows?								
Is there any evidence of tampering with the flow controls?								

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TABLE B.25 SuDS maintenance inspection checklist

Inspection date								
	Details	**Y/N**	**Action required**	**Date completed**	**Details**	**Y/N**	**Action required**	**Date Completed**
Are there any other matters that could affect the performance of the system in relation to the design objectives for hydraulic, water quality, biodiversity and visual aspects? (Specify.)								
Other observations								
Information appended (eg photos)								
Suitability of current maintenance regime								
Continue as current Increase maintenance Decrease maintenance								
Next inspection								
Proposed date for next inspection								

BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

An introduction to sustainable drainage systems or SuDS

SuDS are a new environmentally friendly approach to managing rainfall that uses landscape features to deal with surface water. SuDS aim to:

- control the flow, volume and frequency of water leaving a development area
- prevent pollution by intercepting silt and cleaning runoff from hard surfaces
- provide attractive surroundings for the community
- create opportunities for wildlife.

SuDS at Robinswood Primary School and Matson Park

The SuDS are designed to prevent flooding of Robinswood Primary School and to control the flow of water from springs in Matson Park using attractive landscape features.

- A low bank has been constructed in the park as a dam when water flows down the route of an old ditch during heavy rain.
- The everyday flow from springs above the path in the park has been directed along a new stream in the park, which keeps a new wildlife pond full of water but also allows it to soak into the ground or flow onward to a controlled outfall into the school grounds.
- The controlled outfall into the school grounds allows heavy rainfall to leave the park slowly and make its way through green space above the school playing field.
- Exceptional storms or prolonged heavy rain can overflow from the park across a grass weir on the bank into the “environment space” at the top of the playing field retained by a low bank running along the contour to the old oak tree.
- The school wildlife pond, with a toddler fence around it, gives children in the school an opportunity to learn about animals and plants that live in water and to understand how the SuDS control system works.
- Water will slowly soak into the ground as it travels along the SuDS system, but in exceptional storms some water may overflow down the side of the playing field towards the road as it did in the past but without going through the school first.

Managing the SuDS

The SuDS at Robinswood Primary School have been designed for easy maintenance to comprise:

- regular day-to-day care – litter collection, grass cutting and checking the inlets and outlets where water enters or leaves a SuDS feature
- occasional tasks – managing pond vegetation and removing any silt that builds up in the SuDS features
- remedial work – repairing damage where necessary.

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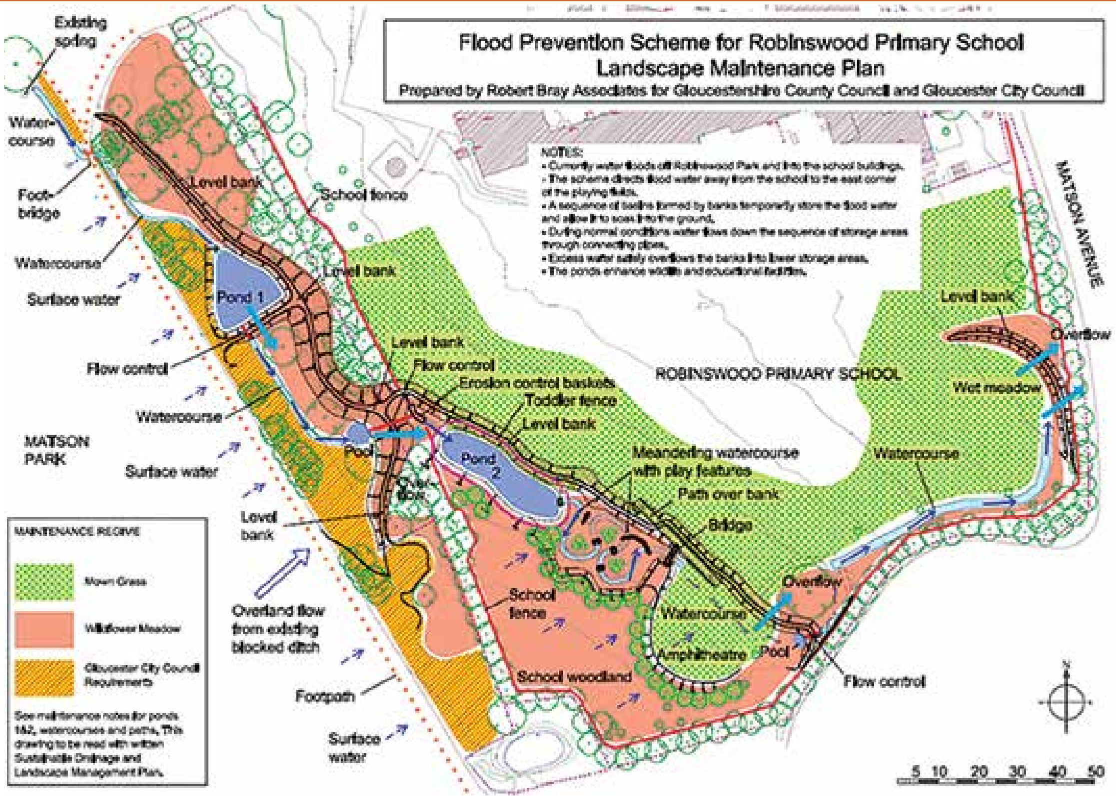
BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**



Matson Park SuDS management

The SuDS sequence begins where the springs emerge above the path, near the park entrance from Underhill Road, and take a changed route under a new bridge to form a stream in the park.

Action:

- Strim or mow grass where the springs emerge and allow vegetation to grow to at least 100 mm or to full height annually in the low flow channel or stream bed.

The new stream carries water to the first wildlife pond (Pond 1 – see site plan).

Action:

- Mow the path verge and grass up to the stream as current practice by GCC.
- Cut stream vegetation annually in September–November, removing cuttings to a wildlife pile or from site.
- Allow grass beyond the stream to develop as meadow and cut at 100 mm September–November removing cuttings to a wildlife pile or from site.

The wildlife pond will develop wetland vegetation round the edge with reasonably short grass towards the park side to allow people to look at the water.

Longer meadow grass on the far side of the pond and beyond the stream will provide a home for wildlife and an opportunity for creative play.

Action:

- Mow the path verge and grass up to the stream and pond edge from park side as current practice by GCC.
- Cut meadow grass beyond stream at 100 mm September–November removing cuttings to a wildlife pile or from site.

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

- Monitor how the pond edge develops, and cut 30% of vegetation at 100 mm each year during September–November, if required, removing cuttings to wildlife piles or from site.
- Occasionally remove pond vegetation, if it spreads across the pond, by hand clearing, raking or machine clearance, using a 1–3 tonne tracked vehicle, with cuttings removed to wildlife piles or from site.
- Check the outlet from the pond and the inlet on the other side of the bank are clear.

The stream flows onward from the pond through grass to a “micropool”, before it leaves the park through a final outlet into the school grounds “environment space” at the top of the playing field.

There is a grass overflow weir over the bank down to the school fence which should be cut annually to ensure that erosion does not occur. Brambles should be allowed to re-colonise the base of the bank on the school side for security reasons.

Action:

- Mow path verge and grass to the stream from the park side as current practice by GCC.
- Cut meadow grass beyond stream at 100 mm September–November removing cuttings to a wildlife pile or from site.
- Cut “micropool” vegetation annually September–November, if required, removing cuttings to a wildlife pile or from site.
- Cut overflow weir as meadow grass at 100 mm September–November removing cuttings to a wildlife pile or from site.

Robinswood Primary School SuDS management

Water from the Matson Park flows slowly through the bank, or overflows over a grass weir in exceptional rainfall. The water arrives on the school site through the fence onto a stone-filled basket channel flowing along a grass swale to the second wildlife pond and “environment space” (Pond 2 see site plan).

Action:

- Strim or mow grass around stone-filled basket channel and along the swale to the pond at 100 mm with grass at maximum height 150 mm.

The school wildlife pond will develop a wetland edge along the 1 m wide wet ledge before rising up to a flat dry ledge (or bench) provided for safety.

Action:

- Allow grass beyond the pond and away from the school side to develop as meadow and cut at 100 mm in September–November removing cuttings to a wildlife pile on site.
- On the school side, cut the grass regularly at 100 mm with grass at maximum height 150 mm for access.
- Monitor pond vegetation and cut 30% of edge at 100 mm each year, if necessary, during September–November, removing cuttings to wildlife piles.
- Occasionally remove pond vegetation if it spreads across the pond by hand clearing or raking being careful not to damage the pond liner.

The water leaves the pond under a small bridge into a swale maze flowing to a flat activity area.

Water leaves the southern end of the environment space through an outlet in the bank with a micropool in front of it.

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

Action:

- Cut the grass in the swale maze channel once each year, September–November, at 100 mm removing cuttings to wildlife piles.
- Cut grass paths, verges and the flat activity area at 35–50 mm with 75 mm maximum, leaving cuttings *in situ* or remove to wildlife piles.
- Cut all other areas within the environment space as meadow cut at 100 mm in September–November removing cuttings to a wildlife pile on site during school summer holiday.
- Check that the outlet and the inlet on each side of the bank is clear.

Should water reach the outlet from the environment space then it will flow down a grass swale, a flat bottomed grass channel, to another holding basin before overflowing slowly through the boundary onto the road.

Action:

- Cut the shallow swale and meadow as part of normal playing field maintenance.

SuDS and landscape maintenance – summary

		Frequency	Unit Rate	Total
Regular maintenance				
1	**Litter management**			
1.1	Pick up all litter in SuDS and landscape areas and remove from site	12 visits monthly		
2	**Grass maintenance – all cuttings to wildlife piles**			
2.1	Mow all grass verges, paths and amenity at 35–50 mm with 75 mm max, leaving grass *in situ*	As required or monthly		
2.2	Mow all dry swales, dry SuDS basins and margins to low flow channels and other SuDS features at 100 mm with 150 mm max Cut wet swales or basins annually as wildflower areas	4–8 visits as required Annually		
2.3	Wildflower areas strimmed to 50 mm in September or at the end of school holidays Or Wildflower areas strimmed to 50 mm on 3 year rotation 30% each year	1 visit annually 1 visit annually		
3	**Inlets and outlets**			
3.1	Inspect monthly, remove silt from slab aprons and debris, strim 1 m round for access	12 visits monthly		
4	Hard surfaces – not applicable			
4.1	Sweep all paving regularly, sweep and suction brush permeable paving in autumn after leaf fall	1 visit		
Occasional tasks				
5	**Inspection and control chambers – not applicable**			
5.1	Annual inspection, remove silt and check free flow	1 visit		

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BOX B.2 Example SuDS Maintenance Plan for Robinswood Primary School

		Frequency	Unit Rate	Total
6	**Wetland and pond vegetation**			
6.1	Wetland vegetation to be cut at 100 mm on 3–5 year rotation, 30% each year, all cuttings to be removed to wildlife piles or from site	As required		
7	**Silt management**			
7.1	Inspect swales, ponds, wetlands annually for silt accumulation	1 visit		
7.2	Excavate silt, stack and dry within 10 m of the SuDS feature, but outside the design profile where water flows, spread, rake and overseed	As required		
8	**Native planting**			
8.1	Remove lower branches where necessary to ensure good ground cover to protect soil profile from erosion	1 visit annually		
Remedial work				
9	**Inspect SuDS system regularly to check for damage or failure** **Undertake remedial work as required**	**As required**		

SuDS scheme checklist

SuDS schemes include landscape features and control structures to manage runoff as it flows to site outfalls. The following lists the SuDS components and extra features which may be found on a site.

- **Filter strips** are grass verges that allow runoff to flow through vegetation to a swale, wetland, infiltration area or other SuDS component.
- **Swales** are linear, flat-bottomed grassed or vegetated channels that convey water from one place to another. They can also store water and allow it to soak into the ground.
- **Underdrained swales** are stone-filled trenches with a perforated pipe in the bottom covered by engineered sandy soil and turf. These intercept dirty water and allow it to soak into the ground or lead it to a water storage feature.
- **Filter drains** clean, store and convey water to another feature or allow it to soak into the ground. They are stone-filled trenches, sometimes with a perforated pipe in the bottom. These may be enlarged to treat dirty water, as treatment trenches, or increase soakage into the ground, as infiltration trenches.
- **Permeable surfaces** are permeable block paving, porous asphalt, gravel or free-draining soils that allow rain to percolate through the surface into underlying drainage layers. They should be protected from silt, sand, compost, mulch etc.
- **Infiltration basins, trenches, soakaways** and most of the preceding SuDS features allow water to soak into the ground.
- **Basins, ponds and wetlands** are depressions in the ground where water is stored and treated. Water levels rise after rain and then drop to the normal level as the excess soaks into the ground or is released slowly to a watercourse or drain. Some water may be held back as a pond for final treatment, amenity or wildlife interest.
- **Bioretention areas** are planted areas with engineered topsoil over drainage layers that allow water to soak into the ground.

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

- **Green roofs** are planted with sedum or other plant material. They clean and absorb water allowing it to evaporate. Excess water is drained from the roof to other SuDS features.
- **Inlet and outlets structures** are often conveyance pipes protected with mesh guards. They should be free from obstruction at all times to allow free flow through the SuDS.
- **SuDS flow control structures** are usually small orifices in control chamber, slots or V-notches in weirs. They are usually near the surface, so are accessible and easy to maintain. They may be in baskets, in small chambers or in the open.
- **Inspection chambers** and rodding eyes are used on bends or where pipes come together. They allow cleaning of the system if necessary.
- **Overflows** can be below ground through gratings and chambers or over grass weirs in the open. They should be kept clear at all times to protect areas from flooding.
- **Flood routes (exceedance routes)** allow water volumes exceeding the capacity of the SuDS system to escape from the site without causing damage to property. This route should be clear of obstructions at all times.

SuDS design usually avoids use of below-ground structures such as gully pots, oil separators and other sumps, which are a wildlife hazard, often ineffective and expensive to maintain. SuDS design also reduces pipework, manholes and interceptors. However, water may be conveyed in surface features such as rills and channels, with changes in level managed in spouts or cascades. These hard landscape features require standard landscape maintenance.

Sustainable drainage maintenance specification

General requirements

General requirements	
Maintenance activities comprise ▪ regular maintenance ▪ occasional tasks ▪ remedial work	Frequency
Generally Litter Collect all litter or other debris and remove it from site at each site visit	Monthly

- **Avoid** use of weed-killers and pesticides, to prevent chemical pollution.
- **Avoid** de-icing agents wherever possible to allow bioremediation of pollutants in permeable surfaces.
- **Protect** all permeable, porous and infiltration surfaces from silt, sand, mulch and other fine particles.

Exclusions

- Maintenance of rainwater harvesting chambers, pumps etc.

Filter strips and swales

- **Filter strips** are grass verges next to hard surfaces that allow runoff to flow through vegetation, removing silt and pollution.
- **Swales** are linear, flat-bottomed grassed or vegetated channels that convey water from one place to another, which can also store water and allow it to soak into the ground.
- **Underdrained swales** are free-draining swales with stone-filled trenches in the bottom covered by engineered sandy soil and turf that clean dirty water and allow it to soak into the ground or lead it to a water storage feature.

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BOX B.2 Example SuDS Maintenance Plan for Robinswood Primary School

Filter strips and swales	
Regular maintenance	**Frequency**
Grass Mow amenity grass access paths and verges surrounding swales and filter strips at 35–50 mm minimum and 75 mm maximum or as specified. Mow filter strips and swales at 100 mm with 150 mm maximum to filter and control runoff in normal grass swales, removing first and last cut in season, and if grass is longer than 150 mm removing cuttings to wildlife piles on site. Where marsh or wetland develops in the swale due to wet conditions then cut annually, or as required, at 100 mm, removing cuttings to wildlife piles on site	Monthly or as required Monthly or as required Annual or as required
Occasional tasks	**Frequency**
Where there is a build-up of silt on the filter strip, swale, underdrained swale or at inlets, ie 50 mm or more above the design level, then remove and spread on site. Undertake when ground is damp in autumn or early spring and transplant turf and overseed to original design levels. Spread excavated material on site above SuDS design profile, eg top of banks, in accordance EA (2010)	As required
Remedial work	**Frequency**
All damage to be made good to design profile unless there is a design flaw	As required

Filter drains

- **Filter drains** are stone-filled trenches, sometimes with a perforated pipe in the bottom, that collect, clean and store runoff before conveying the water to another SuDS feature or allowing it to soak into the ground.
- **Treatment trenches** are enlarged filter drains designed to treat a known volume of dirty water or increase soakage into the ground. They may also be used to intercept overland flows, when they are referred to as **cut off drains**.

Filter drains and infiltration trenches	
Regular maintenance	**Frequency**
Grass edges Mow 1 m min. wide grass surround to drain at 100 mm and 150 mm maximum to filter runoff and protect drain from silt	Monthly or as required
Occasional tasks	**Frequency**
Weeds Hand pull or spot treat individual weed growth, only if necessary, ensuring that weed-killer does not enter the filter drain. Weed growth usually dies in dry weather	As required
Remedial work	**Frequency**
Siltation at surface Where there is no protective geotextile, remove all stone and perforated pipe replacing as original spec. and include separating geotextile as below. Where there is a separating geotextile (see spec.) then remove surface stone layer and separating geotextile that protects the stone drain below. Replace geotextile and top stone layer	As required

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

Pervious pavements

- **Pervious pavements** including permeable block paving, porous asphalt, gravel or free-draining soils that allow rain to percolate through the surface into underlying drainage layers. They should be protected from silt, sand, compost, mulch etc. Permeable block paving and porous asphalt can be cleaned by suction brushing.

Pervious pavements	
Regular maintenance	**Frequency**
Cleaning Brush regularly and remove sweepings from all hard surfaces	Monthly
Occasional tasks	**Frequency**
Permeable pavements: Brush and vacuum surface once a year to prevent silt blockage and enhance design life	Annually
Remedial work	**Frequency**
Monitor effectiveness of permeable pavement, and when water does not infiltrate immediately advise the client of possible need for reinstatement of top layers or specialist cleaning. Recent experience suggests that jet washing and suction cleaning will substantially reinstate pavement to 90% efficiency	As required

Infiltration systems – soakaways, infiltration trenches and infiltration basins

- **Infiltration basins, trenches, soakaways** and most of the preceding SuDS features allow water to soak into the ground.

Soakaways, infiltration trenches and infiltration basins	
Regular maintenance	**Frequency**
Grass edges Mow 1 m min. wide grass surround to drain at 100 mm and 150 mm maximum to filter runoff and protect infiltration structure from silt	Monthly or as required
Infiltration basins Protect grass surface from compaction and siltation and manage main area of basin for design function or appearance	As required
Occasional tasks	**Frequency**
Infiltration basins Where there is a build-up of silt in the basin at inlets (ie 50 mm or more above the design level), remove when the ground is damp in autumn or early spring and turf to the original design levels. Spread excavated material on site above SuDS design profile (eg top of banks), in accordance with EA (2010). **Infiltration trench** Hand pull or spot treat individual weed growth, only if necessary, ensuring that weed-killer does not enter the drain and inhibit natural breakdown of pollutants	As required As required
Remedial work	**Frequency**
Infiltration basin Where the infiltration basin is compacted, reinstate by removal of silt and de-compaction of the surface by scarifying, spiking or the use of hollow tines to the basin area	As required

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

Detention basins, ponds and wetlands

- Detention basins, ponds and wetlands are depressions in the ground that store water. Water levels rise after rain and then drop to the normal level as the excess soaks into the ground or is released slowly to a watercourse or drain. Some water is often held back in a pond or wetland for final "polishing" treatment or amenity interest.
- Detention basins are usually dry.
- Ponds can be permanent or temporary and are mainly open water.
- Wetlands are mainly aquatic vegetation but can have small areas of open water like ponds.

Detention basins, ponds and wetlands	
Regular maintenance	**Frequency**
Grass Mow grass access paths and verges surrounding basins, ponds and wetlands areas at 35–50 mm minimum and 75 mm maximum, or as specified, to provide a cared-for appearance and allow pedestrian access	Monthly or as required
Mow rough grass areas for occasional access or habitat reasons at 100 mm and maximum 150 mm with cuttings removed to wildlife piles	As required, 4–6 times annually
Grass areas not required for access may be managed for wildlife interest and to reduce costs. Two cuts in July and September or one cut annually in September or October as specified, and cuttings removed to wildlife piles	Annually or as required
Wet woodland management Manage annually as detailed spec. with cuttings left in situ or removed to wildlife piles	Annually or as required
Wetland vegetation Cut (strim) at 100 mm with cuttings removed to wildlife piles September–October Or Maintain as a mosaic to be cut 25–30% in any one year at 100 mm in September or October with cuttings removed to wildlife pile	Annually or as required
Occasional tasks	**Frequency**
Where silt accumulates on apron or area in front of inlet or outlet, remove and land apply within design profile of SuDS. Where silt accumulates more than 150 mm in base of wetland, undertake a phased removal of silt subject to client approval. Confirm whether a liner is present to hold water or prevent pollution of groundwater and protect. Remove silt as instructed, but not more than 30% of pond or wetland area at any one time and to an agreed depth but not the subsoil layer. Retain as much representative existing vegetation as possible to ensure rapid re-colonisation of open areas. Stack excavated material adjacent to wetland to allow de-watering of silt. Undertake silt removal during September–October to minimise damage to protected wildlife and ensure regrowth of aquatic vegetation before winter. Spread excavated material on site above SuDS design profile, eg top of banks, in accordance with EA (2010).	Annually or every 3 years, as required

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

Detention basins, ponds and wetlands	
Remedial work	**Frequency**
Although not usually required, this may be needed due to damage to liners or control structures	Undertake as design details or as required

Inlets, outlets, controls and inspection chambers

- **Inlets and outlets structures** may be surface structures or conveyance pipes with guards or headwalls. They should be kept free from obstruction at all times.
- **SuDS flow control structures** can be protected orifices, slots weirs or other controls at or near the surface to be accessible and easy to maintain. They may be in baskets, in small chambers or in the open.
- **Inspection chambers** and rodding eyes are used on bends or where pipes come together and allow cleaning of the system if necessary. They should be designed out of the system where possible.

Inlets, outlets, controls and inspection chambers	
Regular maintenance	**Frequency**
Inlets, outlets and surface control structures Inspect surface structures, removing obstructions and silt as necessary. Check there is no physical damage. Strim vegetation 1 m min. surround to structures and keep hard aprons free from silt and debris	Monthly Monthly
Inspection chambers and below-ground control chambers Remove cover and inspect, ensuring that water is flowing freely and that the exit route for water is unobstructed. Remove debris and silt. Undertake inspection after leaf fall in autumn	Annually
Occasional maintenance	
Check topsoil levels are 20 mm above edges of baskets and chambers to avoid mower damage	As necessary
Remedial work	**Frequency**
Unpack stone in basket features and unblock or repair and repack stone as design detail as necessary	As required
Repair physical damage if necessary	As required

Overflows and flood routes

- **Overflows** are overland across weirs, through gratings or within chambers and should be kept clear at all times to protect areas from flooding. They allow onward flow when part of the SuDS system is blocked.
- **Flood routes (exceedance routes)** allow water volumes that exceed the capacity of the SuDS system to pass through or round the site without causing damage to property. These routes should be clear of obstructions at all times.

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BOX B.2 **Example SuDS Maintenance Plan for Robinswood Primary School**

Overflows and flood routes	
Regular maintenance	**Frequency**
Overflows – Jet the pipes leading from overflow structures annually and check by running water through the overflow. Check free flow at next SuDS feature – inlet to basin or chamber	Annually
Overflows – Remove any accumulated grass cuttings or other debris on top of grass weirs or stone-filled baskets overflows	Monthly
Flood routes – Make visual inspection. Check route is not blocked by new fences, walls, soil or other rubbish. Remove as necessary	Monthly
Remedial	**Frequency**
Overflows – If overflow is not clear then dismantle the structure and reassemble to design detail	As required

Ornamental planting and existing vegetation

- **Ornamental trees** – All ornamental planting to be kept weed free and pruned, using secateurs to keep the shrubs to an agreed and reasonable size.
- **Native trees and shrubs** – All native planting to be allowed to grow freely, removing overhanging branches as required.

Planting and existing vegetation – review	
Regular maintenance	**Frequency**
Grass maintenance	
Amenity grass – Mow all grass verges, paths and amenity grass at 35–50 mm with 75 mm max. All cuttings to remain in situ	16 visits
Rough grass – Mow at 75–100 mm but not to exceed 150 mm All cuttings to wildlife piles	4 – 8 visits
Wildflower areas strimmed to 50 mm in Sept–Oct. Or Wildflower areas strimmed to 50 mm July and Sept. Or Wildflower areas strimmed to 50 mm on 3 year rotation, 30% each year. All cuttings to wildlife piles	1 visit 2 visit 1 visit
Ornamental tree and shrub planting Weed all shrub beds as detailed spec. as necessary. Cut back planting from lights, paths and visibility sight lines in late autumn and as necessary. Cut hedges slightly tapered back from base with flat top at specified height. Do not mulch planting adjacent to permeable or porous paving surfaces. Remove stakes and ties from trees when no longer needed for support and within 3 years of planting. Protect from strimmer damage and remove competitive growth until well established	4 visits

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BOX B.2 Example SuDS Maintenance Plan for Robinswood Primary School

Planting and existing vegetation – review	
Native trees and shrub planting Prune to shape in year 1. Protect trees from strimmer damage and remove competitive growth until well established. Remove stakes and ties from trees when no longer needed for support and within 3 years from planting	1 visit
Existing trees Check existing trees for safety	1 visit
Remedial	**Frequency**
Replace trees and shrubs that fail in the first 5 years after planting. Carry out tree surgery as necessary	

Spillage – emergency action

Most spillages on development sites are of compounds that do not pose a serious risk to the environment if they enter the drainage in a slow and controlled manner with time available for natural breakdown in a treatment system. Therefore, small spillages of oil, milk or other known organic substances should be removed where possible using soak mats as recommended by the Environment Agency, with residual spillage allowed to bioremediate in the drainage system.

In the event of a serious spillage, either by volume or of unknown or toxic compounds, then isolate the spillage with soil, turf or fabric and block outlet pipes from chamber(s) downstream of the spillage with a bung(s). (A bung for blocking pipes may be made by wrapping soil or turf in a plastic sheet or closely woven fabric.)

Contact the Environment Agency immediately.

Queries regarding a design feature

In the event of a concern or failure of a SuDS design feature contact:

Robert Bray Associates, Sustainable Drainage Consultants and Landscape Architects

Fairfield, Coronation Road, Rodborough, Stroud, Gloucestershire GL5 3SB

T: (01453) 764885

F: (01453) 765545

E: bob@robertbrayassociates.co.uk

W: www.sustainabledrainage.co.uk

B.9 ADOPTION HANDOVER CHECKLIST

The objective of this checklist is to ensure that:

- the organisation approving the drainage scheme (drainage approving body) has all the necessary design and other information to allow it to effectively manage the SuDS component or scheme
- the SuDS component or scheme is in an acceptable condition for adoption and will not pose a maintenance or other liability due to poor quality construction or unauthorised changes to the design.

At adoption handover stage, the design should already be approved, and functionality of the SuDS components should not be called into question unless it is the direct result of poor construction or unauthorised changes to the design. The system should have been constructed to the tolerances stated in the approved design and specification (or to accepted industry tolerances such as those stated in the SHW (HA, 2005) in relation to earthworks and road pavement construction or BS 7533-3:2005+A1:2009 for block paving construction). If the system is constructed outside the specified tolerances it may require an assessment of the as-constructed tolerances to determine whether or not it will perform as required.

The adoption handover inspection should be carried out at the end of the 12 month defects liability period (or other specified period). It should supplement the final construction inspection and is not a replacement for the construction inspections. The process should be as shown in **Figure B.2**.

It is likely that phased completion of parts of a SuDS scheme will be necessary on larger systems. The complete scheme may not be delivered until the total build-out is completed (this could take 8–10 years in some cases). However, portions of the scheme for specific sub-catchments will be delivered and will be self-sustaining in their own right. Adopting bodies should adapt the checklist and have procedures in place to allow for this scenario.

Figure B.2 Adoption process

TABLE B.26 SuDS adoption handover checklist

General information	
Site ID	
Site location and co-ordinates (GIS if appropriate)	
Elements forming the SuDS scheme	
Phase of scheme if part of a larger final system	
Specific purpose of any parts of the scheme (eg biodiversity, wildlife and visual aspects)	
Type of development	
Period of developer maintenance (defects liability period)	
Date of assessment	

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TABLE B.26 SuDS adoption handover checklist

Check	Details	Acceptable (Y/N)	Details of corrective action required	Corrective action completed (date)
General				
Design approval checks satisfactory?				
Construction inspection checks satisfactory?				
Asset information				
As-constructed plans and survey submitted?				
As-constructed drainage calculations/models submitted if necessary (eg outside specified tolerances)?				
Proprietary product information submitted, where applicable?				
Asset listed on asset register or database?				
Maintenance information				
Full Maintenance Plan submitted?				
Inspection and maintenance records indicate stated maintenance undertaken during 12 month maintenance period?				
Handover inspection				
Confirm that inlets and outlets are clear.				
Confirm that correct planting in accordance with approved design is fully established.				
Confirm that no uneven settling of soil, channelling, unwanted ponding or erosion of bed or side slopes. If yes, give reason for defect (design or construction).				
Confirm that no evidence of construction sediment or unexpectedly rapid build-up of sediment.				
Confirm that agreed maintenance access is clear.				
Confirm that permeable/porous surfaces are draining effectively and that there is no unacceptable settlement.				
Confirm that any permanent water levels are in accordance with the approved design.				
Suitability for adoption				
Good condition – acceptable Minor defects – acceptable subject to minor works (indicate, with reasons, whether cost should fall to developer or adopting body) Major defects – Not acceptable without substantial repair works (indicate, with reasons, whether cost should fall to developer or adopting body)				

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ASTM E96/E96M-15 *Standard test methods for water vapor transmission of materials*

FTMS 101C-Method 2065 *Puncture Test Federal Test Method Standard*

Image courtesy Peterborough City Council

APPENDIX C DESIGN EXAMPLE: ROSETREE ESTATE

Contents

Appendix C Design example: Rosetree Estate

This design example is based on a hypothetical site, developed to demonstrate:

1 the design process (Chapter 7)

2 the detailed hydraulic and treatment design of individual components (Chapters 11–23).

It does not cover landscape works, amenity or biodiversity design, construction programming and processes, costs and benefits or operation and maintenance requirements, health and safety, community engagement etc. It does not include appraisal of different design options or the evaluation of alternative SuDS components in delivering the required design criteria. The site layout and features have been developed specifically to allow the incorporation of a range of preselected SuDS components and it does not purport to be a realistic development layout.

The example works through the conceptual design of the scheme to meet the design criteria, as presented in this manual, and sizing of a number of representative SuDS components. It does not cover detailed scheme design or component detailing.

C.1 SITE DESCRIPTION

Rosetree Estate is a hypothetical 31 ha greenfield development site in central England, with proposals agreed for mixed use development, including:

A medium-density residential development

B shopping area including a civic street

C large supermarket site

D light industrial area including a factory and a lorry park

E further development area for which there are no current development proposals.

The site will be developed in phases with surface water managed at the sub-catchment level as far as possible. A strategic site drainage system will collect runoff from sub-catchments and local surfaces, and convey it to the River Springbourne to the south of the site.

This design example follows the process set out in **Chapter 7**.

C.2 STAGE 1: STRATEGIC SURFACE WATER MANAGEMENT OBJECTIVES

Pre-application discussions have occurred between the developer and the local planning authority, and an Environmental Impact Assessment and Flood Risk Assessment (FRA) have been undertaken for the development as a whole. Together with initial consultations with the environmental regulator and local community associations, the strategic site surface water management objectives listed in **Table C.1** have been agreed.

TABLE C.1 Strategic surface water management objectives

Delivery area	Strategic objective
Water resource	There are insufficient drivers for residential rainwater harvesting systems. The site is not in an area of water stress and there are good infiltration opportunities for much of the site, which provides a more cost-effective means of managing runoff volumes. The supermarket chain with the right to development on this site has a policy of using rainwater harvesting for all stores and is keen to use the system to manage surface water from the roof to the maximum extent possible.
Flood risk	Rates and volumes of surface water discharge from the site to be controlled to greenfield values, as per the water quantity design standards set out in **Section 3.3**. The FRA requires that there is no encroachment of the development into the existing Zone 3 river floodplain. Roads and the surface water management system are acceptable within Flood Zone 2. The discharge from the SuDS to the River Springbourne will, of necessity, have to be constructed within the Zone 3 floodplain.
Water quality	The River Springbourne at the site is a sensitive water body due to a downstream drinking water abstraction point. Appropriate treatment of surface water discharges will be required.
Amenity	For providing appropriate amenity value in the SuDS design, opportunities include: ▪ a "green" civic street – where planting is a feature of the community space and retail environment and can be incorporated in the SuDS design ▪ a landscaped parkland area that offers amenity and recreational value, where water is a feature and again can be incorporated in the SuDS design.
Habitat and biodiversity	The local biodiversity strategy has identified the need for: ▪ more trees to support specified bird species ▪ wetland areas to replace previous local wetland areas that have been lost, and to enhance and protect amphibian populations. There are habitat corridors that link to the site to the north, and the provision of a habitat link from north to south across the site is important. All of these objectives can be incorporated into the SuDS design.
Climate resilience	The development is in a low density suburban environment. Urban cooling is not, therefore a key driver. However, strategic objectives for water resources, flood risk, habitat and biodiversity will all contribute to climate resilience.
Approval and adoption	The local planning authority will be the approving body for the surface water management system, and will approve the scheme against a set of locally agreed standards (that match those set out in this manual). The local sewerage undertaker has agreed to adopt and maintain the strategic drainage components that lie within public open space, including both surface components and subsurface pipework. The drainage within the commercial and industrial plots will be owned and maintained by the relevant site owners. The soakaways in private gardens will be the responsibility of the property owner.

C.3 STAGE 2: CONCEPTUAL DESIGN

Step 1 Site and development characterisation

Following the guidance set out in **Section 7.5.1**, the characteristics set out in **Tables C.2** and **C.3** relating to surface water management were established for the site and the development respectively. The layout of the site and development are illustrated in **Figures C.1** and **C.2** respectively.

TABLE C.2 Site characterisation outcomes

Site topography	The area comprises gently sloping terrain towards the south-east of the site.
Existing flow routes and discharge points	The site has not been previously developed, so the only unnatural preferential flow routes are those formed by farming patterns. There was, historically, a small ditch running centrally through the site from north to south.
Potential for infiltration	The east of the site overlies low permeability clay soils where maximum groundwater levels are within 1 m of the ground surface. Infiltration will be limited in this area. The soils to the west of the site are sandier and more permeable and groundwater levels are lower. There are opportunities for infiltration in this area. The ground to the north of the site is on the edge of a water supply borehole source protection zone (SPZ1) – which is a separate groundwater body. Groundwater in this area lies approximately 3 m from the surface and is overlain by relatively low permeability silty clayey sand. The site is greenfield and there is no known contamination of the underlying soils in or adjacent to this area.
Potential for surface water discharge	The river supports medium/good water quality. It is classed as sensitive at this location, because of a water supply abstraction point 250 m downstream. Surface water can be discharged to the river providing it has been adequately treated.
Site flood risks	There is an area of floodplain adjacent to the river that encroaches on the development site. Water levels during periods of flooding could pose a risk to the free discharge from the drainage system. This would need to be allowed for in the detailed design of the system. There are no known existing groundwater, coastal or pluvial flood risks on or adjacent to the site.
Existing site land use	The only use of the site before the proposed development was agricultural.
Existing site infrastructure	There are no existing services or other surface or buried infrastructure on the site.
Existing soils	The existing topsoil and subsoil are suitable for use in the SuDS components.
Local habitats and biodiversity	The local biodiversity strategy has identified that the site forms part of a habitat corridor running north–south and that, in general, this region has suffered from a loss of tree species and wetland areas, which has been damaging from an ecosystem/habitat perspective.
Local landscape and townscape	The area is a small agricultural plot within a principally suburban zone. The level of urbanisation intensifies downstream of this site. The local townscape character is mixed but primarily contemporary.

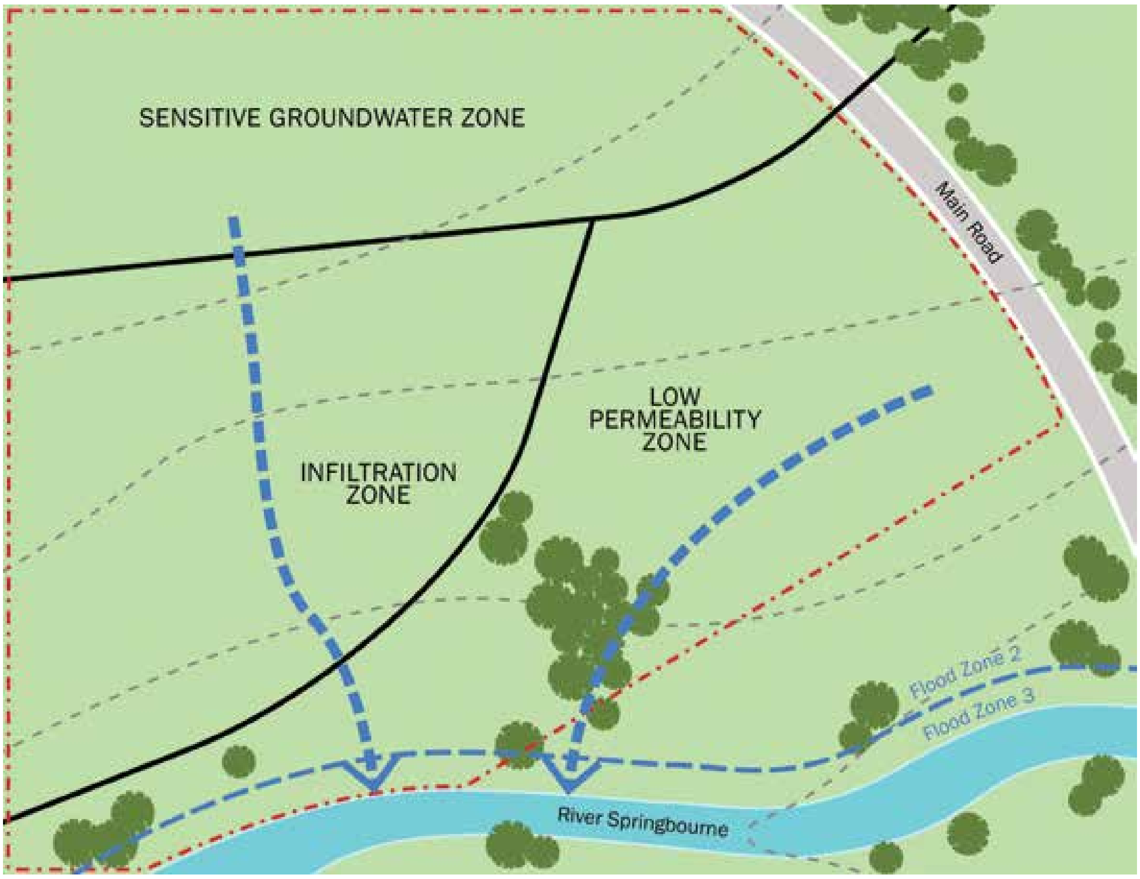

Figure C.1 Site characterisation

TABLE C.3 Development characterisation outcomes

Proposed topography, land use and landscape characteristics	The development master plan has split the area into five sub-catchments using distributor roads. There is likely to be some reprofiling of the site slopes to facilitate construction of the supermarket and industrial areas. The residential and civic street areas will be designed on a gentle slope. The natural drainage patterns on the site have influenced the sub-catchment definition, allowing storage to be provided along the contours to make maximum use of the storage availability across the site. The five sub-catchments reflect different land uses, facilitating the "clustering" of land use types for pollution management purposes. The residential area will include houses at densities of 30–40 houses per hectare with shared parking areas. The civic street will be lined with shops with flats above. Open space will be provided at street level for amenity and retail purposes. To the south-west of the development, closer to the river, the land has been designated as an area of public open space.
Proposed flood risk management strategy	SuDS components can lie within Flood Zone 2, but the combined probability of fluvial and site flooding events will need consideration when checking the impact of flooding on the functionality of the system. SuDS components that are conveying water to the river for discharge can lie in Flood Zone 3.
Proposed site infrastructure	The surface water management system will need to be integrated with the network of proposed services and planned road infrastructure.
Proposed building use, style and form	The civic street requires amenity and biodiversity enhancement with vegetated features and trees. Amenity sports pitches could be used to store volumes of floodwater during extreme events. A green corridor north–south through the site could add significant amenity and biodiversity value and should be used to convey surface water where possible.
Proposed adoption and maintenance	See **Table C.1**.

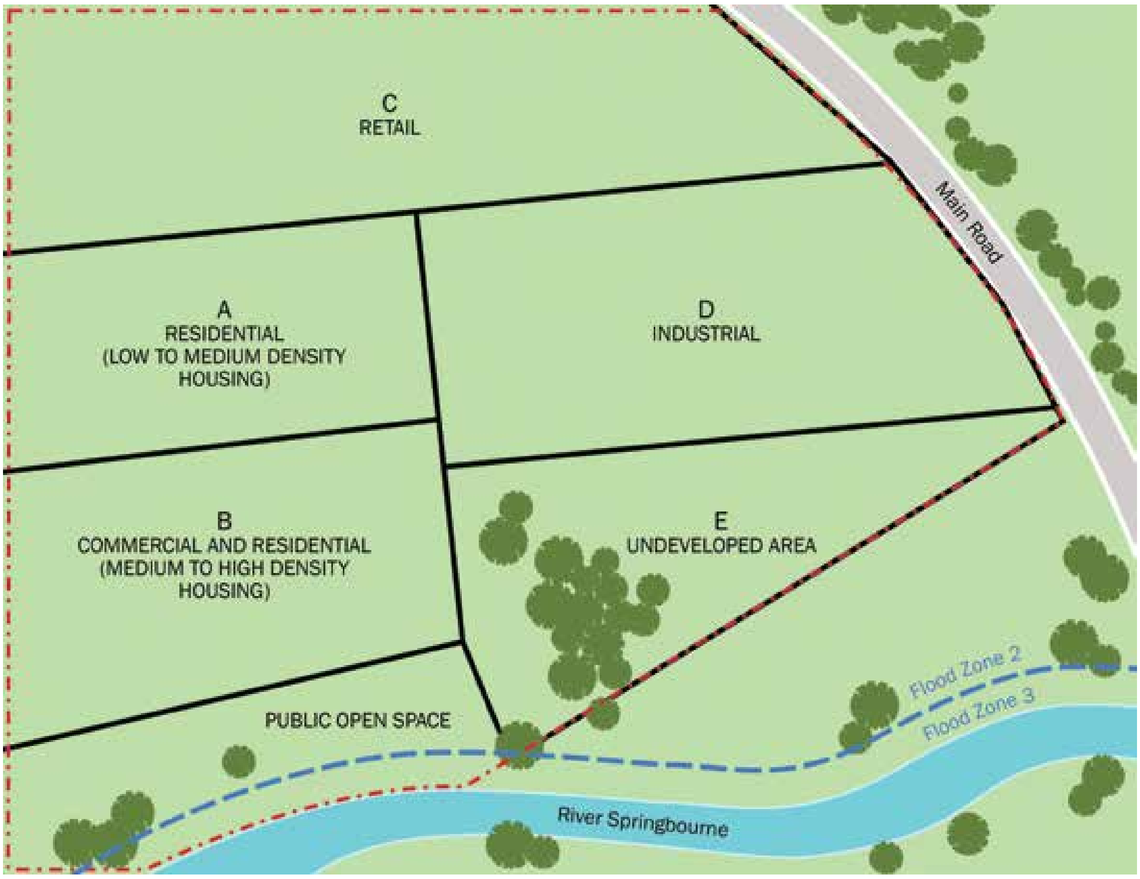

Figure C.2 Development characterisation

Step 2 Establish SuDS design criteria

A suite of design criteria have been established for the scheme in **Table C.4** that take account of:

- the design criteria described in **Chapters 3–6** of this manual
- the strategic surface water management objectives (**Table C.1**)
- the opportunities, constraints and challenges identified by the site and development characterisation process (**Tables C.2** and **C.3**)
- the guidance set out in **Chapters 8–10** of this manual.

TABLE C.4 SuDS design criteria for the site

	Delivery of design criteria
Water quantity	1 Use rainwater harvesting systems where suitable drivers exist (likely to be for the supermarket development only). 2 Control peak runoff rates from the site for the critical 1:100 year event (to meet water quantity standard 2b) using appropriate sub-catchment and strategic system flow controls. 3 Control runoff volumes from the site for an appropriate 1:100 year event (to meet water quantity standard 1b) using rainwater harvesting, infiltration and Long-Term Storage in amenity sports pitch areas. Discharge to groundwater and surface waters, not sewers. 4 Control peak runoff rates from the site for the critical 1:1 year return period event (to meet water quantity standard 2a) from strategic amenity pond discharge to river. 5 Deliver Interception for all hard surfaces on the site (to meet water quantity standard 1a). 6 Recreate the ditch running from north to south through the site as a green corridor for the management of surface water. 7 Ensure that the selected SuDS components drain sufficiently quickly so that the system is prepared for managing further rainfall. 8 Ensure that all surface water is retained within the SuDS components for events up to the critical 1:30 year event and contained within appropriate exceedance routes and storage areas up to the critical 1:100 year event, with 300 mm freeboard to points of potential entry to buildings (to meet water quantity standards 3a and 3b), and to include relevant climate change and urban creep allowances.
Water quality	1 Ensure industrial areas have appropriate pollution control operational processes in place to minimise the risk of serious pollution events occurring. 2 Provide treatment of surface water runoff to meet the requirements of water quality standard 2. 3 Ensure that the impact of periodic extended wet and dry periods (potentially more likely under climate change scenarios) would not invalidate treatment performance. Use drought tolerant grasses and shrubs for filter strips, swales, bioretention areas. Ensure suitable supply of water for tree pits. Check treatment if wetland and pond dry out.
Amenity	1 Integrate car parking, recreational and amenity space, identified green corridors and public open space areas with the surface water management system. 2 Use water to support vegetation to enhance civic space, the road environment and public open space. 3 Keep side slopes to accessible water features, swales and detention basins shallow, easily accessible and easy to maintain. 4 Use trees to provide shade in civic street. 5 Keep water on or at the surface where practical. 6 Incorporate rain play features into playground and use wetlands as educational wildlife resource.
Biodiversity	1 Recreate historic ditch and wetland systems. 2 Enhance tree numbers. 3 Contribute to habitat connectivity through green north–south corridor and link to river floodplain. 4 Use a range of wet or ephemeral (temporarily wet and dry) SuDS components to encourage more diverse and resilient ecosystems.

Step 3 Identify feasible points of discharge

Northern and eastern parts of the site are unlikely to be suitable for infiltration of significant volumes of runoff due to the constraints set out in **Table C.2**. The western areas are potentially suitable for infiltration, so discharge to groundwater would be the preferred destination for runoff in this area. There are no nearby surface water sewers.

Following the discharge prioritisation described in **Section 3.2.3**, the point of discharge of all runoff that cannot be infiltrated will be to the adjacent watercourse (the River Springbourne), provided the appropriate controls and treatment are put in place before discharge.

Step 4 Define surface water sub-catchments and flow routes

The surface water sub-catchments are based around the different land use areas, separated by distributor roads. The flow routes follow the natural drainage paths on the site, re-creating the north–south ditch through the middle of the site and keeping the main east–west flow routes along the road networks (**Figure C.3**). This allows storage to be provided along the contours to make maximum use of the storage availability across the site.

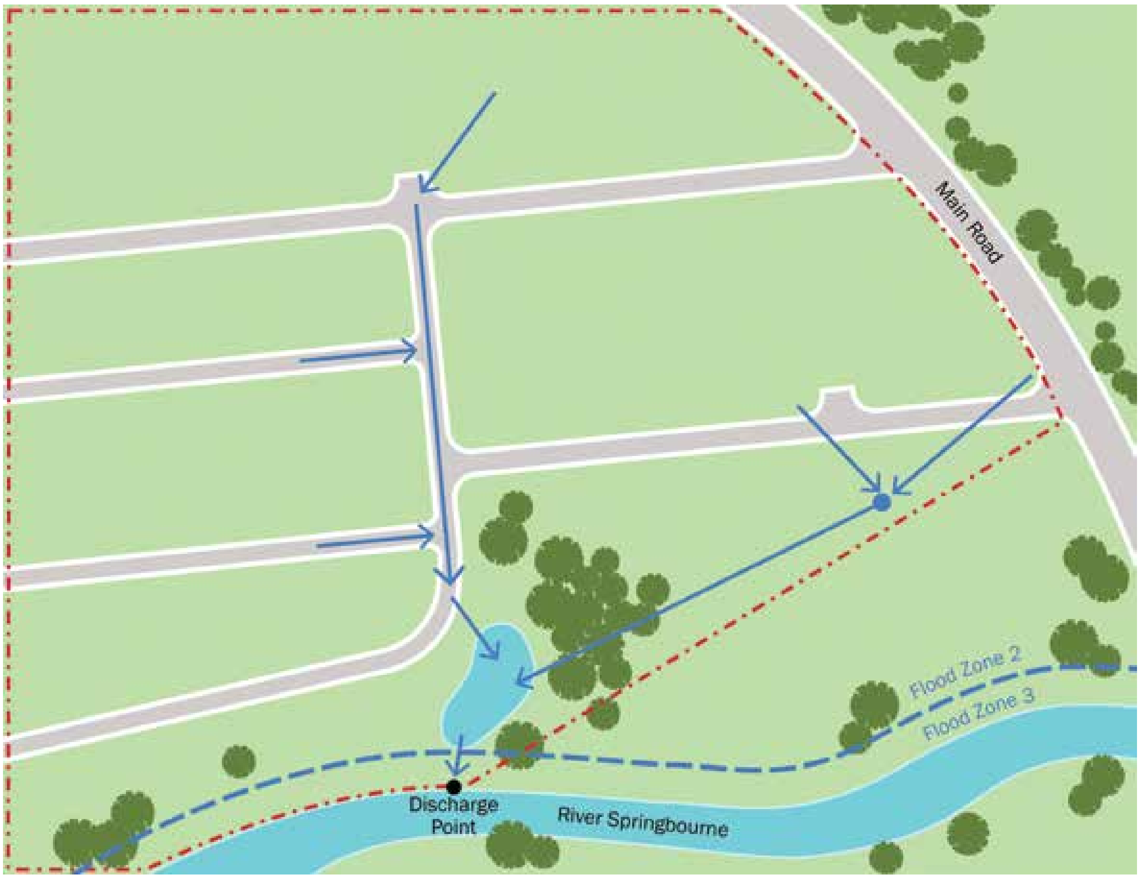

Figure C.3 Main flow routes and discharge points

Step 5 Select SuDS components for the Management Train

The strategic site SuDS components (the central swale conveyance route and the pond/wetland attenuation feature just outside the floodplain of the River Springbourne) should be constructed in advance of any development on the site. Any sub-catchment detention basins should be implemented as part of the site construction surface water management system – managing construction runoff and trapping sediment loads and associated pollution.

SuDS component selection for sub-catchment areas A–D are described below, taking representative areas of each to demonstrate the proposed solutions, that are then sized in **Section C.4.2**.

Residential development (A)

This development area lies over soils suitable for infiltration. It is, therefore, proposed to drain roof areas to individual property soakaways and parking and road areas to concrete block permeable pavement (from which sub-base infiltration is allowed).

TABLE C.5 Selection of SuDS components for residential development (A)

Water quantity	Runoff collection	Standard roof downpipes to soakaway Direct rainfall collection by permeable pavement
	Interception	Infiltration > 5 mm for all surfaces
	Storage	Soakaway (1:10 year minimum) Pavement sub-base (1:10 year minimum, 1:100 year if practicable)
	Conveyance	N/A (exceedance for > 1:10 year event for soakaways)
	Exceedance	Raised kerbs allowing extra storage and conveyance above parking areas and roads
Water quality	Discharges to groundwater (for requirements, see **Table 4.3**)	Residential roofs: Land use hazard: very Low For discharge to standard groundwater: Gross solids and sediment removal
		Residential parking and roads: Land use hazard: low For discharge to standard groundwater: simple index approach required Low hazard indices (**Table 26.2**): TSS: 0.5, metals: 0.4, HCs: 0.4
	Discharges to surface waters	N/A
	Groundwater protection measures	Residential roofs: silt trap
		Residential parking: permeable paving surface plus a minimum of 300 mm underlying soils with good contaminant attenuation potential SuDS mitigation indices (**Table 26.4**): TSS: 0.7, metals: 0.6, HCs: 0.7 (acceptable as higher than hazard indices)
Amenity	N/A	
Biodiversity	N/A	

Civic street (B)

This development area lies over soils suitable for infiltration, though the proximity of buildings, street infrastructure and underlying services means that careful design is required to minimise any risk of adverse effects on the ground below nearby structures. It is proposed to drain roofs and pavement areas to linked tree pits (the trees providing shade and structure to the street), and the roads to bioretention areas (providing zones of enhanced amenity value within the urban space). The bioretention areas will need to be divided with check dams, owing to the slope, and will be used to delineate parking spaces and pedestrian crossing points.

TABLE C.6 Selection of SuDS components for civic street (B)

Water quantity	Runoff collection	Standard roof downpipes and surface channels leading to the tree pits Lateral inflows from roads to bioretention
	Interception	Soil storage, infiltration, evapotranspiration in bioretention and tree pits Bioretention and tree pits drain areas < 25x the contributing runoff area, also designed to infiltrate 1:10 year event
	Storage	Linked infiltration tree pits (1:10 year minimum) Infiltrating bioretention components (1:10 year minimum): surface and subsurface storage
	Conveyance	N/A (exceedance for > 1:10 year event)
	Exceedance	Further storage overlying bioretention areas and within tree pits, raised kerbs allowing extra storage and conveyance above parking areas and roads
Water quality	Discharges to groundwater (for requirements, see Table 4.3)	Residential and small office roofs: land use hazard: very low For discharge to standard groundwater: gross solids and sediment removal
		For commercial roads/parking: land use hazard: medium For discharge to standard groundwater: risk screening approach required. Apply risk screening factors (Table 26.5) RE RS WF 1 1 × 15 (traffic density) 2 1 × 15 (SAAR : < 740 mm) 3 2 × 15 (shallow soakaway) 4 3 × 20 (depth to groundwater 1–5 m) 5 1 × 20 (intergranular flow) 6 1 × 5 (> 15% soil clay content) 7 2 × 5 (1–15% soil organic matter content) 8 1 × 5 (soil pH > 8) Total score = 15 + 15 + 30 + 60 + 20 + 5 + 10 + 5 = 160 Therefore risks to groundwater considered low/medium: simple index approach suitable Medium hazard indices (Table 26.2): TSS: 0.7, metals: 0.6, HCs: 0.7
	Discharges to surface waters	N/A
	Groundwater protection measures	Tree pit provides adequate gross solid and sediment removal
		Roads: bioretention filter medium plus a minimum of 300 mm soils with good contaminant attenuation potential SuDS mitigation indices (Table 26.4): TSS: 0.8, metals: 0.8, HCs: 0.8 (Acceptable as higher than hazard indices)
Amenity	Trees and bioretention planting deliver multi-functional and high amenity road space	
Biodiversity	Trees and bioretention planting provide ecological corridors and valuable habitat for a range of species	

Supermarket (C)

This supermarket development area lies over soils suitable for infiltration, though partly on a zone identified as a source protection zone (SPZ1). There are only small areas of landscaping because maximum allocations of roof and car parking are required by the supermarket.

The drainage system for the site will need to manage the runoff from the following areas:

- the large roof
- an extensive car park
- a delivery area where lorries park while unloading
- an access road within the parking area

The supermarket has a rainwater harvesting policy, so all roof water is, where practicable, to be drained to a rainwater harvesting system, and the operators are keen to add extra storage to this system to provide surface water management benefits. Any overflow from the rainwater harvesting system can be discharged to the ground as the risk is very low and sediment removal will already have occurred. (This was agreed with the environmental regulator as part of the design process.)

The car park could be drained using surface channel systems to bioretention areas and landscaped swales at the edge of the site, with attenuation storage provided in geocellular tanks. An alternative option is to use a permeable pavement system with underlying storage. In this case, permeable paving was the preferred option owing to the need to maximise car parking space. However, the delivery area will drain to a lined detention basin on the perimeter of the site via a proprietary treatment system. (There was not sufficient space to include a vegetated, surface treatment system here, but an extra component was required to remove excess sediments and hydrocarbons to ensure that the quality of water in the basin was appropriate for an amenity feature for the store). The road areas will drain onto the permeable pavement surface.

Due to the underlying SPZ1, infiltration of the car park runoff was not considered to be acceptable without an extra treatment component before discharge. Therefore a liner is proposed and assessments of risks to groundwater are not required.

TABLE C.7 Selection of SuDS components for supermarket (C)

Water quantity	Runoff collection mechanism	Standard roof downpipes to rainwater harvesting and infiltration tank Surface pavement collection for retail parking Service area: channel drain collection
	Interception mechanism	Roof: rainwater harvesting, infiltration Service area: detention basin Car park: sub-base storage, evaporation An additional 0.7 × impermeable area drains to permeable pavement, for which Interception will not be achieved, if pavement is lined Remaining Interception in downstream swale
	Storage	Rainwater harvesting storage tank: size limited by available demand, geocellular soakaway for remainder (1:100 year storage if practicable) Detention basin (1:100 year storage if practicable) Pavement sub-base (1:100 year storage if practicable)
	Conveyance	Piped conveyance to downstream components
	Exceedance	Raised kerbs allowing additional storage and conveyance above parking areas and roads
Water quality	Discharges to groundwater (for requirements, see Table 4.3)	For commercial roofs: land use hazard: low For discharge to protected groundwater: simple index approach, with additional measure Low hazard indices (Table 26.2): TSS: 0.3, metals: 0.2 (tiled roof with no leaching potential), HCs: 0.05

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TABLE C.7 Selection of SuDS components for supermarket (C)

Water quality	Discharges to groundwater (for requirements, see **Table 4.3**)	For service area: land use hazard: medium For discharge to protected groundwater: risk screening Score = 160 (as for Zone B), therefore use simple index approach with extra measure Medium hazard indices (**Table 26.2**): TSS: 0.7, metals: 0.6, HCs: 0.7
		For retail parking: land use hazard: medium For discharge to protected groundwater: as for service area
	Discharges to surface waters (for requirements, see **Table 4.3**)	Required if events up to 1:1 year are not infiltrated owing to the protection required for the groundwater. Simple index approach Medium hazard indices (**Table 26.2**): TSS: 0.7, metals: 0.6, HCs: 0.7
	Groundwater protection measures	For commercial roofs: remove gross solids and sediment (in RWH filtration system) A 500 mm layer of soils that provide good contaminant attenuation potential (Scott Wilson, 2010) is to be provided beneath the infiltration surface at the base of the tank to protect the underlying groundwater SuDS mitigation indices for underlying soils (**Table 26.4**): TSS: 0.4, metals: 0.3, HCs: 0.3, plus additional sediment control This will provide sufficient pollution risk mitigation with the additional sediment control (a position agreed with the environmental regulator)
		For service area: SuDS mitigation indices for lined detention basin (**Table 26.3**) TSS: 0.5, metals: 0.5, HCs: 0.6, plus sediment and hydrocarbon removal in proprietary treatment system, plus a vegetated soil layer with good contaminant attenuation within downstream swale Aggregate these with the SuDS mitigation indices for discharges to groundwater (**Table 26.4**): TSS: 0.5 + 0.5 × 0.6 = 0.8 metals: 0.5 + 0.5 × 0.5 = 0.75 HCs: 0.6 + 0.5 × 0.6 = 0.9 Therefore, with an additional measure in the form of a proprietary product, infiltration from downstream swale is acceptable
		For retail parking area: SuDS mitigation indices for lined permeable pavement (**Table 26.3**) TSS: 0.7, metals: 0.6, HCs: 0.7 Aggregate these with the SuDS mitigation indices for discharges to groundwater (**Table 26.4**): TSS: 0.7 + 0.5 × 0.6 = >0.95 metals: 0.6 + 0.5 × 0.5 = 0.85 HCs: 0.7 + 0.5 × 0.6 = >0.95 Therefore this is suitably conservative to allow infiltration from downstream swale
	Surface water protection measures	Any discharges from this plot to surface waters will undergo on-plot treatment plus further treatment in both the downstream swale and the amenity pond downstream, so a high level of protection will be delivered by the system
Amenity	Rainwater harvesting provides climate resilience Trees in zones between permeable car park areas to provide cooling and shade Improve amenity value of detention basin with selected planting	
Biodiversity	Use trees in zones between permeable car park areas and selected planting in detention basin to maximise biodiversity delivery	

Industrial area (D)

This area lies over low permeability soils (infiltration rate of the order of 1 × 10^{-6} m/s), so infiltration is not viable as a disposal method.

Amenity is not a key driver for this sub-catchment, but vegetated areas will add economic value to the site, and contribute to biodiversity, while delivering water quantity and water quality criteria.

The large roof area will require significant attenuation, which can be provided cost-effectively in attenuation tanks that lie beneath the car park area.

The hard external surface for the factory will require surface treatment components, so that spills or other unexpectedly high pollutant loads can be identified and cleaned up easily. An underdrained swale against the boundary of the site will provide treatment, conveyance and some storage, followed by a small wetland zone.

The adjacent lorry park will also require surface-based treatment, but safety concerns over lorry turning and open channels in this area means that a filter strip and filter drain around the edges are the preferred options.

TABLE C.8 Selection of SuDS components for industrial area (D)

Water quantity	Runoff collection mechanism	Standard roof downpipes to attenuation tank Lateral inflows from parking areas to filter strip and swale
	Interception mechanism	Vegetated components (lined at depth where necessary)
	Storage	Attenuation tank, swale, wetland (no flooding on the site for the 1:30 year event)
	Conveyance	Filter strip direct to filter drain, swale underdrainage to convey runoff to downstream wetland, pipes to amenity pond
	Exceedance	Land profiling allowing additional storage and conveyance above parking areas and roads
Water quality	Discharges to groundwater (for requirements, see Table 4.3)	Industrial roof runoff: n/a
		Factory hard surfacing: high hazard: pre-permitting advice required from environmental regulator Agreement secured that, if high-risk loading bays are covered and drained to foul, all other areas can be considered as per medium risk Therefore, for discharge to groundwater: risk screening Score = 160 (as for Zone B), therefore use simple index approach Medium hazard indices (Table 26.2): TSS: 0.7, metals: 0.6, HCs: 0.7
		Lorry park: high hazard: pre-permitting advice required from environmental regulator Agreement secured that if two downstream treatment components are provided and lined before any allowable infiltration, then licensing can be avoided
	Discharges to surface waters (for requirements, see Table 4.3)	Industrial roof runoff: low hazard: simple index approach Low hazard indices (Table 26.2): TSS: 0.3, metals: 0.2 (an inert roof is proposed), HCs: 0.05

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TABLE C.8 Selection of SuDS components for industrial area (D)

Water quality	Discharges to surface waters (for requirements, see Table 4.3)	For both factory hard surfacing and lorry park: pre-permitting advice required from environmental regulator Agreement secured that licensing can be avoided, if simple index approach used with an additional level of protection before discharge Factory surfacing: medium hazard indices (Table 26.2): TSS: 0.7, metals: 0.6, HCs: 0.7 Lorry park: high hazard indices (Table 26.2): TSS: 0.8, metals: 0.8, HCs: 0.9
	Groundwater protection measures	Industrial roof runoff: not infiltrated
		Factory hard surfacing: vegetated swale (Table 26.3) plus underlying infiltration trench with underlying minimum 300 mm depth of soil with good contaminant attenuation potential (Table 26.4) SuDS mitigation indices for: TSS: 0.5 + 0.5 × 0.4 = 0.7 Metals: 0.6 + 0.5 × 0.4 = 0.8 HCs: 0.6 + 0.5 × 0.4 = 0.8 Acceptable
		Lorry park: n/a
	Surface water protection measures	Industrial roof runoff: sediment trap facility before attenuation tank storage considered sufficient, subsequent discharge via attenuation pond.
		Factory surfacing: swale plus wetland (Table 26.3) (note that wetland will not be a constructed surface flow wetland, so indices assumed to be as for ponds) mitigation indices for: TSS: 0.5 + 0.5 × 0.7 = 0.85 metals: 0.6 + 0.5 × 0.7 = 0.95 HCs: 0.6 + 0.5 × 0.5 = 0.85 Downstream attenuation pond provides additional protection required by regulatory pre-permitting advice
		Lorry park: filter strip plus filter drain plus wetland (see note above) SuDS mitigation indices for: TSS: 0.4 + 0.5 × 0.4 + 0.5 × 0.7 = 0.95 metals: 0.4 + 0.5 × 0.4 + 0.5 × 0.7 = 0.95 HCs: 0.5 + 0.5 × 0.4 + 0.5 × 0.5 = 0.95 Downstream attenuation pond provides additional protection required by regulatory pre-permitting advice
Amenity	Green space on site, seating for employees near wetland area	
Biodiversity	Dry grass areas and wetland provide varied biodiversity	

Step 6 Optimise the Management Train

The scheme is reviewed against the design criteria, and notes added for use in detailed design to ensure that benefits are maximised and suitable calculations and checks are undertaken, including an assessment that the space required for the proposed components is available on the site, and that components are located at a suitable distance from building footprints.

Step 7 The conceptual design

Figure C.4 shows the conceptual SuDS design for the site.

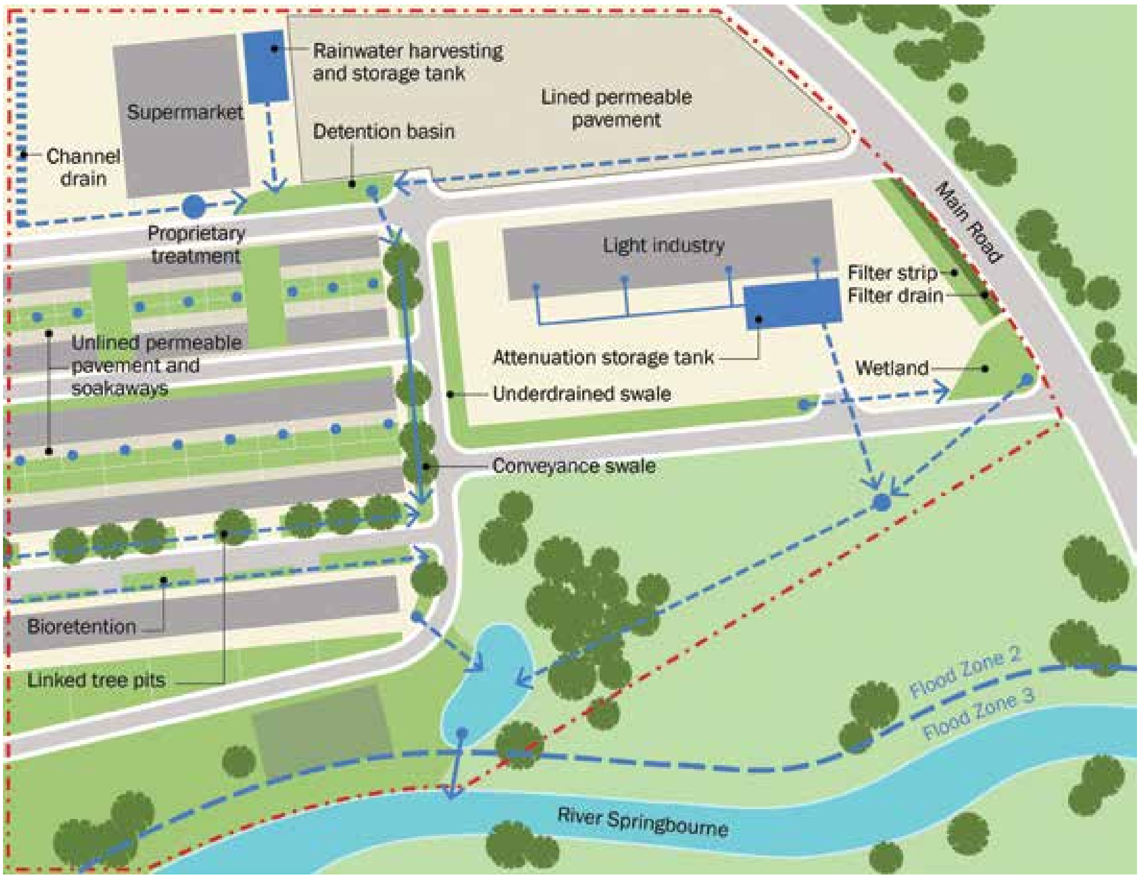


Figure C.4 Overview of proposed SuDS components and Management Train

C.4 STAGE 3: OUTLINE DESIGN

C.4.1 Size SuDS components at site scale

Step 1 Estimate allowable peak site discharge rates

Rosetree Estate is a 31 ha greenfield development site. The standard that is set for the site is that peak flow rates for the 1:1 year and 1:100 year events should be controlled to the equivalent for the greenfield site.

The hydrological characteristics of the region are:

SAAR (mm)	556
SOIL factor	0.37
Hydrometric area	5

Guidance set out in **Chapter 24** should be followed for runoff rate estimation. Greenfield runoff rates can be estimated using FEH methods (**Section 24.3.1**). However, for simplicity, they are estimated here using the IH124 equation (**Section 24.3.2**) as follows:

$$Q_{BAR(rural)} = 0.00108\ AREA^{0.89} \times SAAR^{1.17} \times SOIL^{2.17}$$

As shown in **Equation 24.3 (Section 24.3.2)**, since the site is less than 50 ha, the formula should be applied for 50 ha and the result factored based on the ratio of areas.

$$Q_{BARrural} = 0.00108 \times 0.5^{0.89} \times 556^{1.17} \times 0.37^{2.17}$$

= 0.11 m^3/s

= 110 l/s for 50 ha site

= 110/50

= 2.2 l/s/ha

Although the whole site measures 31.1 ha, there is 2.4 ha of land adjacent to the floodplain which will be parkland and will drain directly to the river at greenfield rates without the need for storage. Therefore the area to be considered in these calculations is 31.1 ha – 2.4 ha = 28.7 ha.

The total allowable Q_{BAR} from the site is therefore: 2.2 × 28.7 = 63 l/s.

To get the 1:1 and 1:100 year allowable peak flow rates, the growth curve factors from **Table 24.2** are used:

1 year factor = 0.87

30 year factor = 2.55

100 year factor = 3.56

Greenfield limiting discharge rates for the site are therefore as given in **Table C.9**.

TABLE C.9 Greenfield runoff rates

Return period	Whole site (l/s)	Unit value (l/s/m²)
1 year	55	0.00019
30 year	161	0.00056
100 year	224	0.00078

These discharge limits will be required at detailed design stage, to size the flow control components for each sub-catchment and from the amenity attenuation pond.

Step 2 Estimate whole site attenuation storage volumes

There are two methods of undertaking preliminary assessments of the attenuation storage volumes required for a site (**Section 24.9.4**). For simplicity, the Kellagher (2013) approximate approach is used here.

TABLE C.10 Catchment development details

Sub-catchment	A Residential	B Civic street	C Supermarket	D Industrial	E Not developed	Roads	Open*	Total
Area (ha)	6.5	4.5	6.2	5.6	4.4	1.5	2.4	31.1
PIMP (%)	75	85	85	65	75	70		77
Impermeable area (ha)	4.9	3.8	5.3	3.6	3.3	1.1		22
Impervious area drained to infiltration systems (ha)	4.9	3.8						8.7
Return period for infiltration system design (years)	10	10						
Impervious area drained to rainwater harvesting systems (ha)			0.9					0.9
Return period for rainwater harvesting system design (years)			100					

Note

* Will drain direct to floodplain without need for storage.

Using the catchment characteristics and design assumptions stated in **Table C.10**, this outputs the required attenuation storage volumes for the whole site as:

Site 100 year attenuation storage volume = 16,000 m^3 or 0.056 m^3/m^2 drained area

This includes a climate change allowance.

Step 3 Long-Term Storage (LTS) volume estimate

Using the equation from **Equation 24.10** (**Section 24.10.2**):

$$Vol_{xs} = RD \times A \times 10 \left[\frac{PIMP}{100} (\alpha\, 0.8) + \left(1 - \frac{PIMP}{100}\right)(\beta\, SPR) - SPR \right]$$

where:

Vol_{xs} = extra runoff volume of development runoff over greenfield runoff, in cubic metres (m^3)

RD = rainfall depth for the 1:100 year, 6 hour event, in millimetres (mm) = 72 mm

$PIMP$ = impermeable area as a percentage of the total area, in per cent (%) = 77

A = area of the site, in hectares (ha) (excluding area that drains direct to river and is not altered by development) = 28.7

SPR = “SPR” index for the SOIL or HOST class (specified as a decimal proportion). This specifies the proportion of runoff from pervious surfaces. (If SPRHOST values are used, then the minimum value should be set to 0.1) = 0.37

α = proportion of paved area draining to the network (values 0–1) with 80% per cent assumed runoff = 0.9 (assumption)

β = proportion of the pervious area draining to the network or directly to the river (values 0–1) = 1.0 (assumption)

Therefore approximate difference in runoff volume between developed and greenfield scenarios for 1:100 year, 6 hour event Vol_{xs} = 5569 m^3

Assuming sub-catchments A, B and roof of C do not require volume control as sufficient volume control is delivered via infiltration and rainwater harvesting, the area requiring volume control is reduced by 11.9 ha (6.5 ha area A + 4.5 ha area B and 0.9 ha roof area C) to 16.8 ha.

Therefore the remaining LTS required = 5569 x 16.8 / 28.7 = 3260 m^3

Remove Interception for all of the remaining impervious areas for which volume control is not provided, ie area C (excluding roof area) + area D + area E + roads = 12.4 ha

Interception volume = 5 mm x 12.4 ha = 620 m^3

Therefore required LTS = 3260 – 620 = 2640 m^3

= 8800 m^2 @ 0.3 m depth

(Note: a football pitch is approximately the same area, so this could be used to store the extra volume.)

There is no need for a climate change allowance when comparing runoff volumes.

C.4.2 Size SuDS components at sub-catchment scale

Step 4 Estimate peak sub-catchment discharge rates

The same approach as Step 1 is undertaken for each of the sub-catchments to estimate peak greenfield runoff rates from each of the areas, in order that sub-catchment attenuation can be implemented where possible (**Table C.11**). This ensures that the space on the site is used most effectively.

TABLE C.11 Greenfield runoff rates for each of the sub-catchments

		Whole site	A Residential	B Civic street	C Supermarket	D Industrial	E Not developed
	Area (ha)	**28.7**	**6.5**	**4.5**	**6.2**	**5.6**	**4.4**
Return period	1 year (l/s)	54.8	12.4	8.6	11.8	10.7	8.4
	Q_{BAR} (l/s)	63.0	14.3	9.9	13.6	12.3	9.7
	30 year (l/s)	154.4	35.0	24.2	33.3	30.1	23.7
	100 year (l/s)	224.3	50.8	35.2	48.5	43.8	34.4

Note

Greenfield runoff rates could be evaluated using individual sub-catchment hydrological characteristics (where there are significant differences in levels of permeability across the site) to optimise the design at detailed design stage, but unit site rates are more likely to be adopted at conceptual design stage.

Step 5 Sub-catchment storage volume estimates

An estimate of the attenuation storage likely to be required for each sub-catchment (provided either within that sub-catchment or in downstream components) is undertaken by factoring the site attenuation storage estimate by the sub-catchment areas (**Table C.12**).

It is estimated that these storage volumes can be provided within the proposed components, within the space available for the development.

Any storage not provided at sub-catchment level will need to be incorporated into the downstream amenity pond.

TABLE C.12 Sub-catchment attenuation volumes

Sub-catchment	Area (ha)	Required total 1:100 year attenuation storage volume (m³)[1]	Contributions to attenuation storage reduction[2]
A	6.5	3624	Infiltration up to 1:10 year event for soakaways, and potentially greater for pavement
B	4.5	2509	Infiltration to 1:10 year event
C	6.2	3456	Rainwater harvesting to 1:100 year
D	5.6	3122	
E	4.4	2453	
Roads	1.5	836	

Notes

1 Equivalent to 0.056 m^3/m^2 (0.05575) drained area

2 Stated 1:100 year storage volume in this table does not take into account these reductions

Step 6 Check flow control points and exceedance flow routes

Initial assessments of flow control points and exceedance flow routes are undertaken for the purposes of initial detailed design calculations (**Figure C.5**). These will require confirmation during design optimisation (normally done using a hydraulic simulation model for a development of this size and complexity), which is not detailed here.

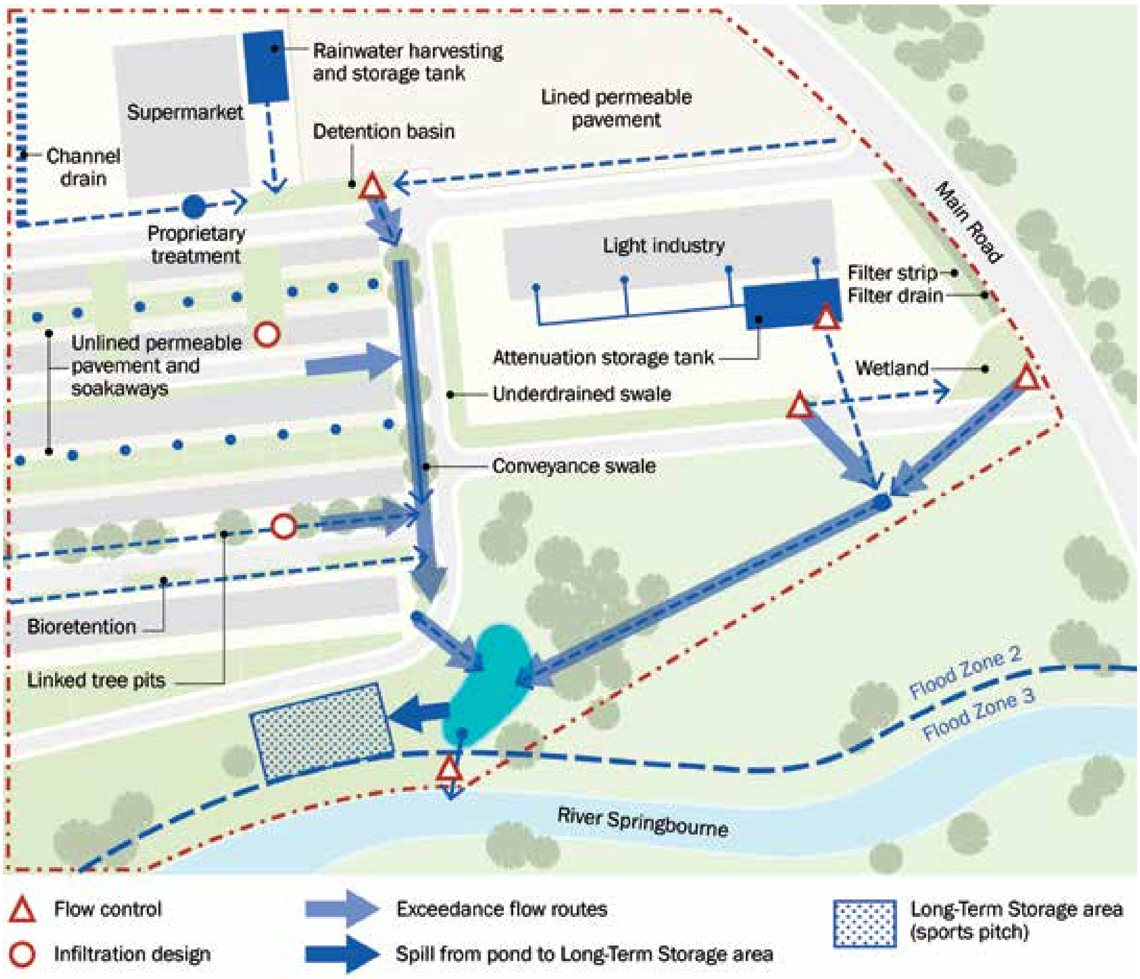


Figure C.5 Proposed flow controls and exceedance flow routes

C.5 STAGE 4: DETAILED DESIGN

The "critical duration" is the length of rainfall event that results in the greatest flow rate, flood volume or flood level (depending on the purpose of the analysis) at a particular location. The critical duration will probably be different at different points in the drainage system, with different SuDS components having different critical durations. The complexity of the site means that it would require detailed modelling to find the critical duration rainfall event for each of the components. Rainwater harvesting systems and infiltration systems will have very different critical duration events from swales or detention basins, and this cannot be easily established using simple hand calculations.

Some representative flow rates and volumes have therefore been assumed in order to demonstrate the technical design of each of the components.

C.5.1 Residential development (A)

A1 Residential soakaway

This example follows the design method for infiltration systems that is described in **Chapter 25**.

A geocellular soakaway system is proposed for the individual house soakaways that allows infiltration from both the vertical sides and the base. Therefore the procedure in **Equation 25.5** for 3D systems is used (**Section 25.6.2**). The design could also be undertaken using commercially available drainage design software. The design is for a 1:10 year rainfall event. Each soakaway will be required to drain a roof area of 150 m^2 (ie the roof of a single house).

Step 1 Estimate infiltration rate

A site investigation was carried out across the residential development area in Area A to confirm the conceptual design assumption that there were silty sands beneath the area that would be suitable for infiltration.

The investigation included infiltration tests that followed the guidance in BRE (1991) (**Section 25.3**). The tests were spread evenly over the residential area and were carried out at a depth and with a head of water similar to the anticipated design layout of the soakaway. All the tests were repeated three times at each location.

The results of the testing are summarised in **Table C.13**.

TABLE C.13 Summary of infiltration test results for residential area

Test location/ reference	Infiltration rate (lowest of the three tests) (m/s)	Soil description over zone where infiltration was occurring	Comment
SA01	1.2×10^{-5}	Silty sandy gravel	Infiltration rate is consistent with soil descriptions
SA02	2.6×10^{-5}	Silty sandy gravel	Infiltration rate is consistent with soil descriptions
SA03	1.2×10^{-3}	Silty sandy gravel with lenses of sandy gravel	Higher infiltration rate is influenced by sandy gravel lenses so not representative.
SA04	7.3×10^{-6}	Clayey sandy gravel	Infiltration rate is consistent with soil descriptions
SA05	1.9×10^{-5}	Silty sandy gravel	Infiltration rate is consistent with soil descriptions

There are insufficient tests to allow statistical analysis so a precautionary approach was taken and the lowest measured value of infiltration rate of 7.3×10^{-6} m/s was used for the design. This design value for the infiltration rate was approved by an experienced ground engineering professional.

A factor of safety was then applied to the infiltration rate to account for possible long-term reductions in performance. **Table 25.2** (**Section 25.6**) indicates that a factor of safety (FOS) of 1.5 is appropriate for a drained area of 150 m^2 and minor inconvenience or damage if the capacity of the soakaway is exceeded (exceedance routes from the area drained by soakaways have been considered in the site layout).

The factored design infiltration coefficient (q) is 7.3×10^{-6} m/s ÷ 1.5 = 4.9×10^{-6} m/s.

= 0.018 m/h

Step 2 Estimate suitable soakaway dimensions

Rectangular geocellular systems are proposed for the design with a porosity (n) of 0.95. The invert level of the incoming downpipes will be 0.8 m below ground level. The soakaway dimensions will be 2 m × 2 m × 2 m.

Step 3 Check the maximum likely depth of water in the soakaway for the design rainfall event, for the proposed soakaway dimensions

(i) Calculate the base area, A_b, and the perimeter, P, from the proposed dimensions

$A_b = 4$ m^2

P = 8 m

(ii) Calculate b

where:

$$b = \frac{P\,q}{n\,A_b}$$ (**Equation 25.4, Section 25.6.2**)

n = porosity = 0.95

q = assumed infiltration rate = 0.018 m/h

b = $(8 \times 0.018)/(4 \times 0.95) = 0.038$ h^{-1}

(iii) Select a range of storm durations and determine corresponding rainfall intensity and h_{max}

h_{max} is calculated for a range of durations from 5 minutes up 24 hours.

where:

$$a = \frac{A_b}{P} - i\frac{A_D}{P\,q}$$ (**Equation 25.4**), A_D = area of drainage area = 150 m^2

$$h_{max} = a\left[e^{(-bD)} - 1\right]$$ (**Equation 25.4**)

TABLE C.14 Depth of water in the soakaway for different event durations (1:10 year)

Duration, D	Duration (h)	Intensity, i, (mm/h)	a (m)	b (h^{-1})	h_{max} (m)
15 min	0.25	65.56	−67.79	0.038	0.64
30 min	0.5	39.4	−40.54	0.038	0.76
45 min	0.75	29.3	−30.02	0.038	0.84
60 min	1	23.7	−24.19	0.038	0.90
2 hours	2	14.3	−14.40	0.038	1.05
6 hours	6	6.4	−6.17	0.038	1.26
24 hours	24	2.2	−1.79	0.038	1.07

Therefore the critical duration event, for which the depth of water is greatest, is approximately 6 hours.

Step 4 Check viability of soakaway dimensions

The largest value of h_{max} is 1.26 m, the depth of soakaway required is therefore 1.3 m. Assuming the incoming pipe is 0.8 m below ground level, then the soakaway will need to be 2.1 m deep. Because the minimum depth to the maximum groundwater levels over Area A is at least 3.1 m, this is acceptable. This provides an unsaturated soil depth below the soakaway of 1.0 m with a freeboard between the maximum water level in the soakaway and the ground surface of 0.8 m.

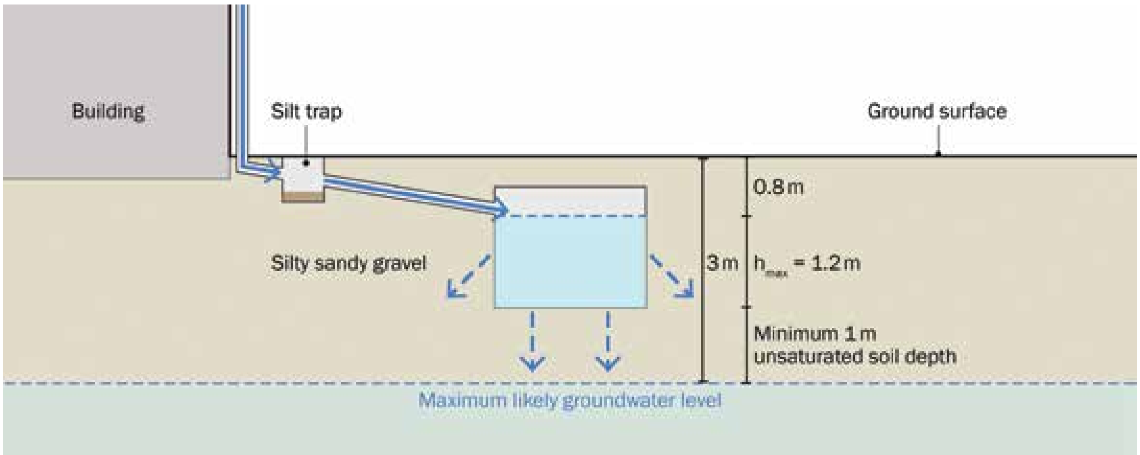


Figure C.6 Residential soakaway

Step 5 Check half emptying time

The time taken for this soakaway to drain down to half full may be found in **Equation 25.6** for a 3D system.

Time to half empty, $t_{1/2}$ =

$$\frac{n\,A_b}{q\,P}\log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right]$$

Therefore $t_{1/2}$ = 12 hours

This is less than 24 hours and is therefore acceptable.

A2 INFILTRATING PERVIOUS PAVEMENT

A concrete block permeable paving system is proposed for the car parks in the residential development which allows infiltration from the base of the pavement construction into the ground below. This example follows the design method for planar infiltration systems that is described in **Chapters 20 and 25**. The parking areas will be a maximum of 12.5 m by 16 m. Note that the calculations would be similar for other types of surfacing material (porous asphalt or concrete) with the exception that Step 3 below would refer to the relevant table for the surfacing material in **Chapter 20**.

Structural design

Step 1 Estimate subgrade strength

The ground conditions at formation level (ie immediately beneath the base of the pavement) comprise silty sandy gravels. Laboratory testing has determined that it is non-plastic. From **Table 20.4** (**Section 20.9.3**), the guideline equilibrium CBR value for the pavement is 7%. The actual subgrade CBR value will require confirmation by site testing when the subgrade is exposed during construction (**Section 20.9.3**).

Step 2 Determine loading category

The pavement design is for small residential car parks that will be trafficked by cars or light commercial vehicles. There may be very occasional HGVs that end up turning or parking in the car park, but there will not be any regular HGV traffic. The site is therefore classified as Site Category 4 (**Table 20.5, Section 20.9.4**).

Step 3 Determine construction thickness

The construction thickness requirements are taken from **Table 20.10** (**Section 20.9.6**) for traffic category 4, as follows:

- 80 mm concrete permeable pavers
- 50 mm bedding layer 2/6.3 aggregate
- 300 mm sub-base coarse-graded aggregate (CGA), which acts as the water storage layer.

The CBR is greater than 5% and therefore subgrade improvement is not required.

Hydraulic design

The system allows infiltration from the base of the pavement. Infiltration from the sides is negligible as the depth is so shallow. Therefore the infiltration design procedure described in **Equation 25.2** (**Section 25.6.1**) for plane systems is used. The design could also be undertaken using commercially available drainage design software. The hydraulic design is for a 1:100 year rainfall event. Climate change allowance will be managed by exceedance routing to the site pond.

The site is flat and the pervious pavement does not take runoff from any adjacent areas, so no adjustment to the depth of the sub-base CGA will be required. The CGA sub-base will be constructed using 4/20 material which typically has a porosity (n) of 0.3.

Step 4 Estimate likely infiltration rate

This process is described in **Section C.5.1** (A1 for residential soakaways). This gives a design infiltration coefficient (q) of 4.9×10^{-6} m/s or 0.018 m/h.

Step 5 Confirm pavement system type

The infiltration rate is greater than 1×10^{-6} m/s and therefore a system type A (total Infiltration) may be used (**Table 20.1, Section 20.3**).

Step 6 Check the maximum likely depth of water in the pavement for the design rainfall event, for the proposed soakaway dimensions

Select a range of storm durations and determine corresponding rainfall intensity and h_{max}.

h_{max} is calculated for a range of durations from 5 minutes up 24 hours

where (from **Equation 25.1, Section 25.6.1**)

where the drainage ratio, $R = A_D/A_b = 200/200 = 1$

$$h_{max} = \frac{D\,(R\,i - q)}{n}$$

TABLE C.15 Depth of water in the pavement for different event durations

Duration, D	Duration (h)	Intensity, i, (mm/h)	h_{max} (m)
15 min	0.25	150.32	0.11
30 min	0.5	86.60	0.11
45 min	0.75	62.80	0.11
60 min	1	50.00	0.11
2 hours	2	28.80	0.07
6 hours	6	12.03	−0.12
24 hours	24	3.76	−1.14

The largest value of h_{max} is 0.11 m which occurs during a 15, 30, 45 and 60 minute storms. The depth of CGA sub-base of 300 mm required for the traffic loads is therefore sufficient for the hydraulic design.

Step 7 Check viability of pavement dimensions

As the minimum depth to annual maximum groundwater levels over area A is at least 3 m, this is acceptable. This provides an unsaturated soil depth below the soakaway of at least 1.0 m with a freeboard between the maximum water level and the ground surface of 0.35 m (the total pavement thickness is 430 mm).

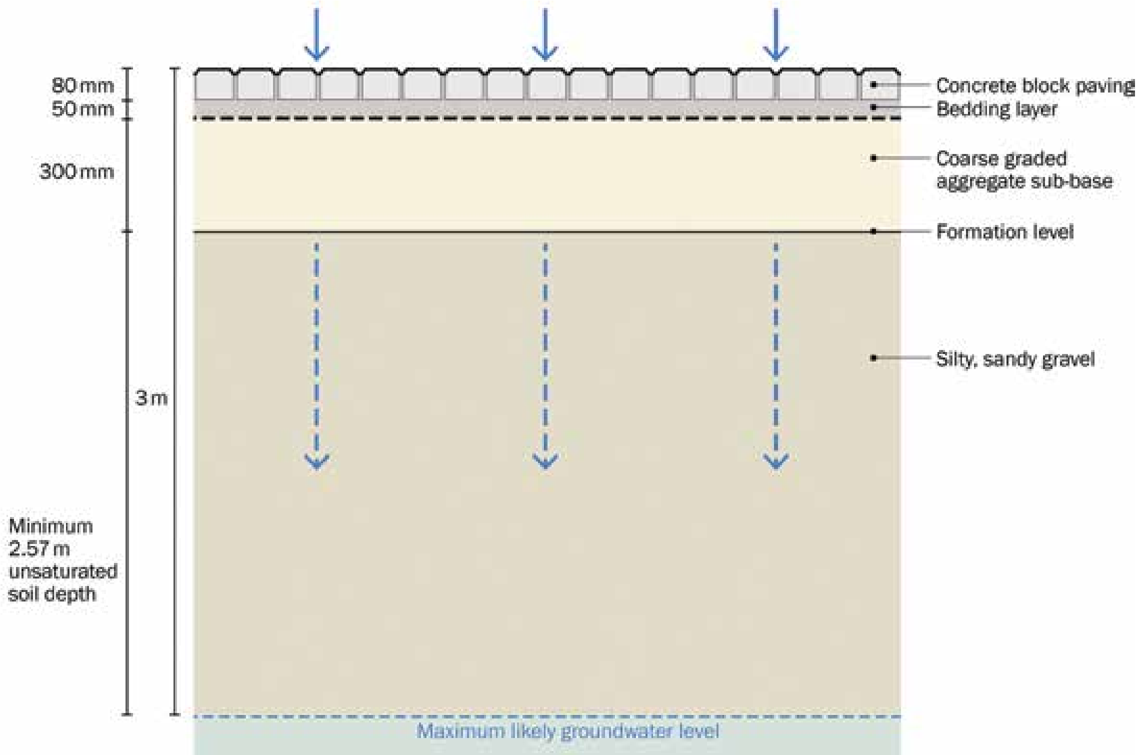


Figure C.7 Residential infiltration permeable block pavement

Step 8 Check half emptying time

The time taken for this soakaway to drain down to half full may be found in **Equation 25.6** (**Section 25.7**) for a plane system.

Time to half empty, $t_{1/2} = (n \times h_{max})/2q$

Therefore, $t_{1/2} = 0.9$ hours

This is less than 24 hours and is therefore acceptable.

C.5.2 Civic street (B)

B1 INFILTRATION TREE PITS

Tree pits are only able to drain small areas due to their limited size, although they do require a certain monthly volume of runoff to keep them alive and support growth.

A system of linked tree pits is proposed to drain the pedestrian areas of the civic street.

Each tree pit will be designed to drain a 10 m by 5 m area of pedestrian surface.

Each tree pit will be constructed using a suitable tree soil. The tree pits will be designed to infiltrate the 1:10 year event.

Step 1 Initial tree pit sizing and characteristics

Each rectangular pit will have a maximum depth to the base of 1 m. The surface area of each pit will be 2 m by 6 m. This volume of soil has been determined by an arboriculturist to suit the needs of the proposed tree species. An extra storage layer below the pit will be provided using 0.5 m thick open-graded aggregate such as Type 4/20 material.

Step 2 Water flow into pit and through the tree soil

Tree pit soil specification in **Box 19.3** gives limits on the permeability of the soil between 25 mm/h and 115 mm/h.

Each pit will have a surface depression where water will be temporarily stored before if flows down through the tree pit soil. This depression will be sized to hold the excess water from a 1:1 year, critical duration event (assumed here to be a 15 minute event) – for water quality treatment. Events greater than this can flow directly to the drainage layer via an overflow.

The rainfall intensity for the 1:1 year, 15 min event is 20 mm/h.

Volume of runoff entering the pit (assuming a runoff factor of 0.9) over 15 minutes:

$= 0.9 \times 50 \times (20/1000) \times 15/60$

$= 0.225\ m^3$

Volume of water soaking into the tree soil over 15 minutes assuming permeability of tree pit soil is 25 mm/h:

$= 12 \times 0.025 \times 15/60$

$= 0.075\ m^3$

Therefore, the storage depth required on the surface of the pit = (0.225 − 0.075)/12 = 0.012 m

Provide a 100 mm deep depression to store water on surface of pit.

Step 3 Estimate likely infiltration rate

Ground conditions in the civic street area are slightly different from the adjacent residential development area and comprise a mantle of head deposits (about 2 m thick) overlying chalk marl. The head deposits comprise clayey (sometimes very clayey) slightly silty sand. The chalk marl comprises silty clay. This was proven to a depth of 3.85 m below ground level by the site investigation. During this investigation no groundwater was encountered.

Three infiltration tests were undertaken in the area where the tree pits are proposed. Two tests were in the shallow head deposits and one in the underlying chalk marl. The results of the testing are summarised in **Table C.16**.

TABLE C.16 Summary of infiltration test results for civic street area

Test location (depth)	Test number	Soil infiltration rate (q)	Soil description over zone where infiltration was occurring	Comment
SA01 (1.0 m)	Test #1	6.88×10^{-6} m/s	Head deposits – very clayey (sometimes clayey) slightly silty sand	Infiltration rate is consistent with soil descriptions
	Test #2	3.16×10^{-6} m/s		
	Test #3	1.08×10^{-6} m/s		
SA02 (1.0 m)	Test #1	4.23×10^{-4} m/s	Head deposits – very clayey (sometimes clayey) slightly silty sand	Infiltration rates are not consistent with soil description and appear high for a very clayey sand. May be localised less clayey (ie more permeable) area. Do not use these results for design as they are not representative of the whole mass.
	Test #2	8.33×10^{-5} m/s		
	Test #3	2.39×10^{-5} m/s		
SA03 (2.5 m)	Test #1	Test failed – did not achieve 75% or 25% effective depth	Chalk marl – silty clay	Stratum is not suitable for infiltration drainage

Consideration of the ground conditions and the tests indicates that there is a shallow layer beneath the development that is suitable for some infiltration. However, the full lateral extent is not known and it is underlain by clay that is not suitable for infiltration. There is only 1 m of the sand between the base of the 1 m deep pit plus 0.5 m deep drainage layer and the chalk marl. This will limit the volume of water that the head deposits can accept.

Therefore the tree pits will be designed as an infiltration system, but with an overflow system to collect and convey the runoff for exceedance events greater than a 1:10 year event to downstream components.

Table C.16 shows that for the second and third tests, the infiltration reduced each time. Using the lowest value from the test in SA01 gives a site infiltration rate of 1.08×10^{-6} m/s.

A factor of safety was then applied to the infiltration rate to account for possible long-term reductions in performance. Table 25.2 indicates that a FOS of 1.5 is appropriate for a drained area of 50 m^2 and minor inconvenience or damage if the capacity of the tree pit is exceeded (exceedance routes from the area drained by the tree pits have been considered in the site layout).

The design infiltration coefficient (q) is therefore 1.08×10^{-6} m/s ÷ 1.5 $= 7.2 \times 10^{-7}$ m/s

= 0.0026 m/h

Step 4 Estimate suitable tree pit dimensions

Rectangular pits are proposed for the design 2 m × 6 m × 1.5 m deep. The aggregate drainage layer will have a porosity of 0.3.

Step 5 Check the maximum likely depth of water in the tree pit for the design rainfall event, for the proposed tree pit dimensions

(i) Calculate the base area, A_b, and the perimeter, P, from the proposed dimensions

$A_b = 12$ m^2

P = 16 m

(ii) Calculate b

where: $b = \frac{P\,q}{n\,A_b}$ (**Equation 25.4**) n = porosity, q = assumed infiltration rate

b = (16 × 0.0026)/(12 × 0.3) = 0.012 h^{-1}.

(iii) Select a range of storm duration and determine corresponding rainfall intensity and h_{max}

h_{max} is calculated for a range of durations from 5 minutes up 24 hours.

where: $a = \frac{A_b}{P} - i\frac{A_D}{P\,q}$ (**Equation 25.4**), A_D = area of drainage area = 50 m^2

$$h_{max} = a\left[e^{(-bD)} - 1\right]$$ (**Equation 25.4**)

TABLE C.17 Depth of water in the tree pit for different event durations

Duration, D	Duration (h)	Intensity, i, (mm/h)	a (m)	b (h^{-1})	h_{max} (m)
15 min	0.25	65.56	−78.05	0.012	0.23
30 min	0.5	39.4	−46.61	0.012	0.28
45 min	0.75	29.3	−34.47	0.012	0.31
60 min	1	23.7	−27.74	0.012	0.33
2 hours	2	14.3	−16.44	0.012	0.39
6 hours	6	6.4	−6.94	0.012	0.48
24 hours	24	2.2	−1.89	0.012	0.47
48 hours	48	1.2	−0.69	0.012	0.30

Therefore the critical duration event, for which the depth of water is greatest, is approximately 6 hours.

Step 6 Check viability of soakaway dimensions

The largest value of h_{max} is 0.48 m, which occurs during a 6 hour storm. The depth of water is less than the depth of the proposed drainage layer and therefore below the level of the tree soil which will minimise the risks of the soil becoming saturated. An overflow pipe that discharges to a system of underdrains will be provided above the level of the drainage layer.

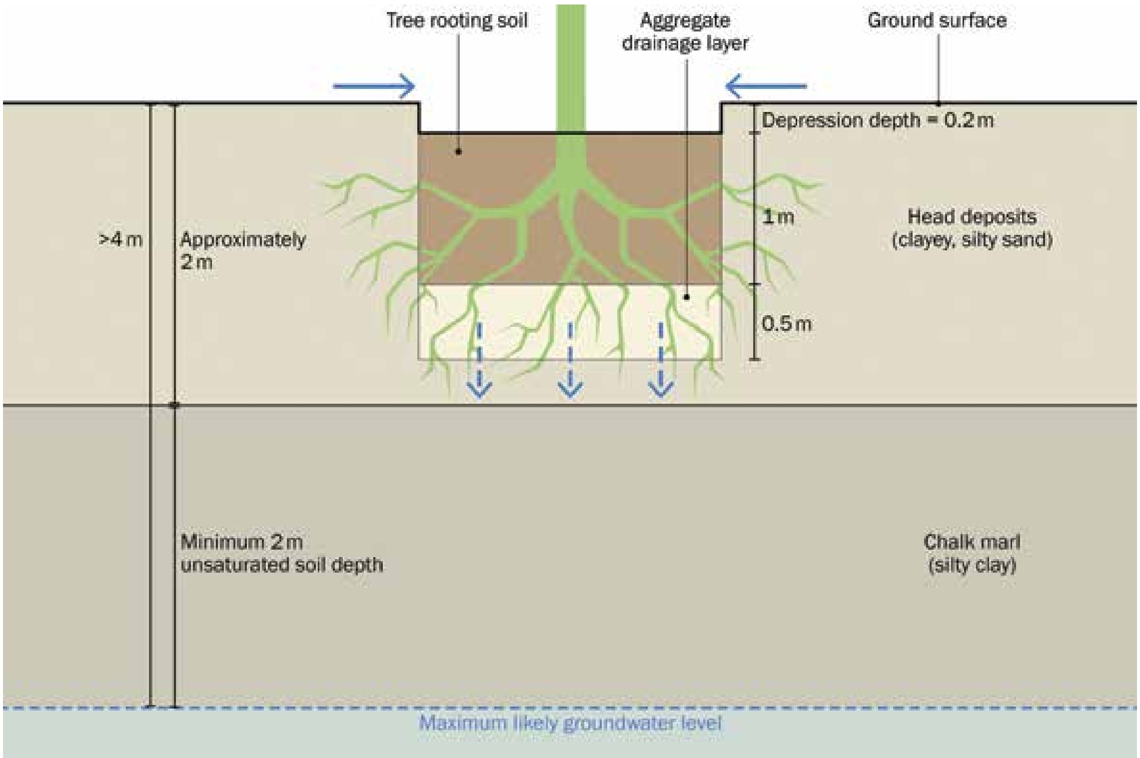


Figure C.8 Civic street infiltration tree pit

Step 7 Check half emptying time

The time taken for the proposed tree pits to drain down to half full may be found from in **Equation 25.6** for a 3D system.

Time to half empty, $t_{1/2}$ =

$$\frac{n\,A_b}{q\,P}\,log_e\left[\frac{h_{max}+\frac{A_b}{P}}{\frac{h_{max}}{2}+\frac{A_b}{P}}\right]$$

Therefore $t_{1/2}$ = 19 hours

This is less than 24 hours and is therefore acceptable. However, if the time to drain exceeded 24 hours this may still be acceptable as it would provide more water to be available for the tree which would be removed by evapotranspiration at some times of the year. The decision to use longer drain down times would have to be made in conjunction with an arboroculturist.

B2 Infiltration bioretention system

Bioretention systems are proposed for drainage of the trafficked areas of the street in the civic street area.

Step 1 Estimate suitable bioretention dimensions and characteristics

It is proposed that the bioretention components are designed using a raised outlet. When full, they will discharge to downstream SuDS components, although normal operation is to dispose of the water via infiltration and evapotranspiration.

The bioretention system will drain a 500 m^2 area of road (which is less than the recommended maximum of 0.8 ha – see **Section 18.2**) and needs to provide treatment for the 1:1 year, critical duration rainfall event (assumed to be 15 minutes).

The proposed surface area of each component is 20 m^2 (which, as a percentage of drained area, = 20/500 = 4%. This is within the recommended range of 2% to 4%).

The proposed characteristics of the system are summarised in **Table C.18**.

TABLE C.18 Design characteristics for bioretention components

Plan area of system (2 m by 10 m)	20 m^2
Depth of extended detention for water quality treatment event (depression storage)	200 mm
Filter material depth	800 mm
Coefficient of permeability of filter material	100 mm/h
Drainage layer depth	200 mm
Drainage perforated pipe diameter	100 mm
Half of maximum allowable surface water depth	100 mm
Required time to half drain (48 h)	172,800 s

Step 2 Hydraulic design

Check inflow velocity

The proposed inlet to the bioretention components is a 1 m wide dropped kerb. Assuming a runoff factor of 0.9, the maximum inflow rate for the 1:1 year, 15 minute duration event (which has a rainfall intensity of 20 mm/h) will be:

$$Q_{in} = 500 \times 0.9 \times 20 \times 10^{-3} \div 3600 = 0.0025 \text{ m}^3/\text{s}$$

Using Manning's equation (**Equation 24.12, Section 24.11.1**), assuming a hydraulic roughness coefficient of 0.03, and a slope of 1/60 gives the following depth: velocity: flow relationship

TABLE C.19 Depth velocity relationship for bioretention inlet

d (mm)	V (m/s)	Q (m^3/s)
2	0.068	0.0001
5	0.126	0.0006
10	0.200	0.0020
20	0.317	0.0063
30	0.415	0.0125
40	0.503	0.0201
50	0.584	0.0292

A flow rate of 0.003 m^3/s will therefore have a velocity of about 0.23 m/s at a depth of about 12 mm. This velocity is < 0.5 m/s (recommended maximum in **Section 18.4.1**).

(ii) Check surface area of filter bed and time to drain down

Using **Equation 18.1** (**Section 18.4.1**) with a rainfall intensity of 20 mm/h.

Assuming 90% runoff, the volume of water requiring treatment is calculated as follows:

$$V_t = 500 \times (20/1000) \times 0.9 \times 15/60 = 2.25 \text{ m}^3$$

The required filter surface area is calculated as follows:

$$A_f = \frac{V_t\, L}{k(h + L)t}$$

where:

A_f = surface area of filter bed (m^2)

V_t = volume of water requiring treatment (m^3) = 2.25 m^3

L = filter bed depth (m) = 0.8 m

k = coefficient of permeability of filter medium for water (m/s) = 0.1 / 3600

h = average height of water above filter bed (half maximum height) (m) = 0.1 m

t = time required for water quality treatment volume to percolate through filter bed (s) = 48 × 3600

Therefore:

$$\frac{2.25 \times 0.8}{0.000028\ (0.1+0.8) \times 172800} = 0.41\ m^2$$

The bioretention provided has an area of 20 m^2 and is therefore acceptable. A smaller area should not be used as it will increase the risk of the surface clogging.

Step 3 Check the maximum likely depth of water for the design rainfall event, for the proposed dimensions

A check is undertaken using the same procedure as outlined for the infiltrating tree pits, which confirms that the drainage layer has sufficient storage for the 1:10 year event.

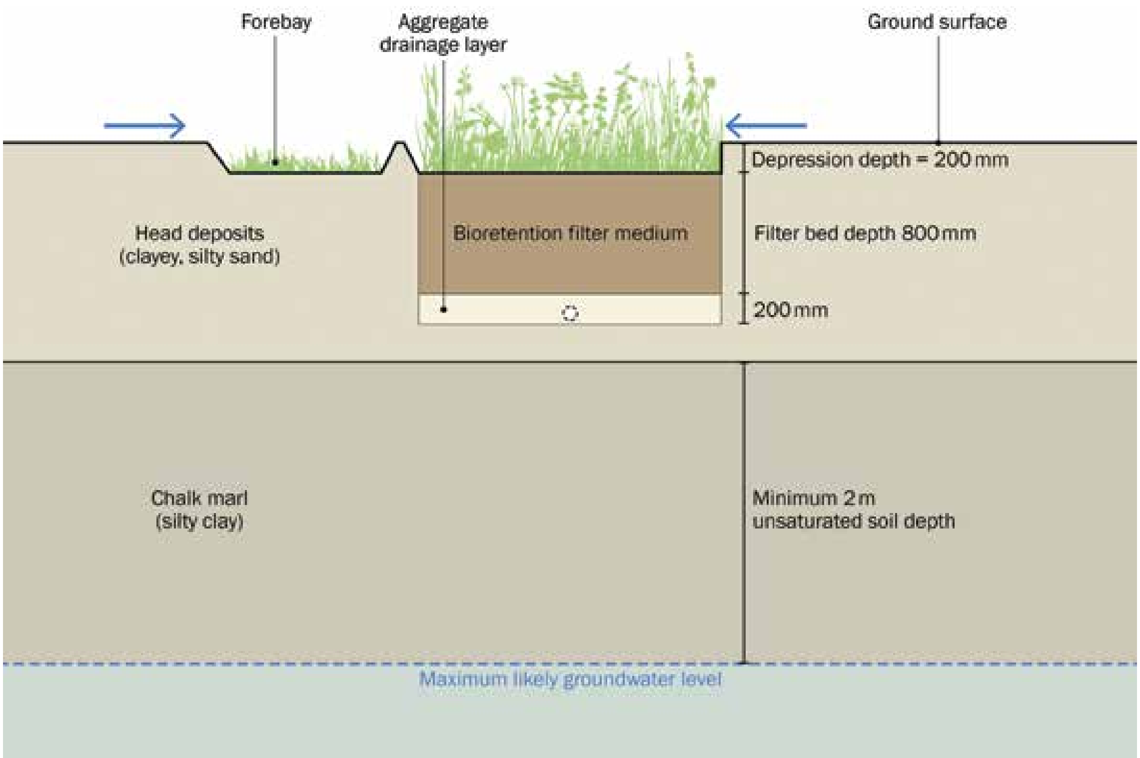


Figure C.9 Civic street infiltration bioretention systems

Step 4 Undertake forebay design

To protect the long-term performance of the bioretention system, a small forebay area is proposed immediately downstream of the dropped kerb inlets.

Using **Equation 18.2** (**Section 18.8.1**), the volume of the forebay is determined using the following equation:

$$V_s = A_c\ R\ L_o\ F_c$$

where:

V_s = volume of forebay sediment storage required (m^3)

A_c = contributing catchment area (ha) = 500/10000 = 0.05 ha

R = 0.8

L_o = 3.1 m^3/ha/y (based on 5000 kg/ha/yr – from Wilson *et al* (2004) for AADT of 5000–15000 and a density of 1600 kg/m^3)

F_c = 5 years

Therefore, volume of forebay = 0.05 × 0.8 × 3.1 × 5 = 0.6 m^3

The area of the forebay is determined using the following equation which is modified from Fair and Gayer (1954):

$$R = 1 - \left[1 + \frac{v_s\ A_f}{n\ Q}\right]^{-n}$$

where:

R = 0.8 target value

v_s = settling velocity for coarse sediment (63 micron to 500 micron) = 0.07 m/s at 10°C (from Hall *et al*, 1993) (which is based on Stoke's Law).

Q = 1:1 year 15 minute event flow into system = 0.0025 m^3/s based on 20 mm/h rainfall intensity

A_f = 1 m^2 (assume a 1 m^2 area is provided as a forebay)

n = 0.5

Proportion of sediment captured

$$R = 1 - \left[1 + \frac{0.07 \times 1}{0.5 \times 0.0025}\right]^{-0.5}$$

R = 0.87 which is greater than target value of 0.8

Therefore, a small 1 m^2 forebay is sufficient.

However, for a forebay of these dimensions with the sediment loading rate above, the sediment depth accumulated in the component = 0.6 m^3/1 m^2 = 0.6 m which is too deep.

To limit to 200 mm depth, the forebay area must be increased to 3 m^2 or the contributing area reduced (ie a greater number of systems provided).

Step 5 Check capacity of the underdrains is sufficient.

The underdrains should then be designed using standard pipe design methods (not covered here). The flow capacity along the pipes should be checked, as well as the flow capacity into the perforations (taking account of the permeability of any geotextile surround).

Step 6 Landscape and biodiversity design

Once the basic layout and dimensions are achieved, the planting and specific detailed layout and materials would be designed by the landscape architect or planner to fit the overall streetscape.

C.5.3 Supermarket (C)

C1 Rainwater harvesting system

The supermarket is keen to use harvested rainwater for non-potable uses on the site and to size the rainwater harvesting system to manage surface water runoff from the roof as far as possible.

Roof runoff poses a very low risk to groundwater, and the excess runoff that cannot be harvested will spill to a separate tank for infiltration.

Designing the rainwater harvesting system to manage surface runoff follows the guidance in **Chapter 11, Section 11.3.3**.

Step 1 Check that the demand (volume to be used) will exceed the yield (runoff volume from the roof)

1 Estimate demand (of non-potable water)

Toilet use

$$D_N = P_d\, n \times 365$$

where:

D_N = total annual property demand for non-potable water (l)

P_d = daily demand per person (l)

n = number of occupants in the property

Number of people using the store per day:	8000
% of people who use the toilet:	5%
Volume used per flush:	6 l
Daily demand:	(5/100) × 8000 × 6 = 2400*

* This figure is assumed to include staff use

Surface wash down

Volume used for daily washdown:	400 l
Total annual demand, D:	(2400 + 400) × 365 = 1,022,000 l

2 Estimate yield (runoff from roof)

where:

$$Y_R = A\, e\, AAR\, \eta$$

Y_R = runoff volume (yield) (l)

A = collecting runoff area (m^2)

e = runoff (yield) coefficient

AAR = average annual rainfall depth (mm)

η = hydraulic filter efficiency (ratio)

Roof area:	9000 m^2
Annual average rainfall:	556 mm
Roof runoff coefficient:	0.95
Filter coefficient:	0.9

Total annual yield, Y: 9000 × (556/1000) × 0.95 × 0.9 × 1000 = 4,278,420 l

3 Yield: Demand ratio, Y_R/D_N = 4.2

The Y_R/D_N ratio needs to be < 0.95 for effective surface water management. Therefore, the maximum area of roof from which runoff can be harvested is

= (0.95 × 1,022,000)/(0.556 × 0.95 × 0.9 × 1000) = 2042 m^2

The roof area is split naturally into two independent sections, one of which has an area of 1900 m^2. Therefore, this smaller area is drained to the rainwater harvesting system, and the remaining roof area is drained to a separate soakaway tank (not designed here).

Step 2 Estimate the rainwater harvesting storage tank capacity required to deliver both supply and surface water management

Y_R/D_N for the system (where the contributing roof area = 1900 m^2) is 0.88, therefore the detailed method design approach has to be taken (**Box 11.6, Section 11.3.3**).

$V_{total} = V_{SC}$

$V_{SC} = ((R_d - SP50 + Ad) \times A/(CP50 \times 1000)) + 1.0$

R_d = net effective rainfall depth of the design storm (mm) (ie design storm depth × design event filter and runoff coefficients = 60 mm × 0.95 × 0.9 = 51.3 mm

Net rainfall depth that is served by a 1 m^3 storage tank (mm), SP50 = (1/A) × C_s × 1000

Cs is a coefficient which is a function of $Y_R/D_N = -0.677 \times (Y_R/D_N) + 1.40$ (if Y_R/D_N ratio is between 0.6 and 0.9 for AAR < 750 mm and r > 0.35)

Cs = (−0.677 × 0.88) + 1.40

= 0.80

SP50 = (1/1900) × 0.80 × 1000

= 0.42

Extra net rainfall depth allowance to cater for the uncertainty of storage availability for the design storm event:

$Ad = 31.06\,(Y_R/D_N)^2 + 15.08\,(Y_R/D_N) + 0.36$

$Ad = 31.06 \times (0.88)^2 + 15.08 \times (0.88) + 0.36$

= 37.68 mm

The CP50 value takes into account the fact that the effective storage volume provided is less than the actual storage:

$CP50 = -3.29\,(Y_R/D_N)^2 + 4.16\,(Y_R/D_N) - 0.3$

(if Y_R/D_N ratio is between 0.6 and 0.9 for AAR < 750 mm and r > 0.35)

$CP50 = -3.29 \times (0.88)^2 + 4.16 \times (0.88) - 0.3$

= 0.81

Tank size required for surface water management

V_{sc} = [((51.3 − 0.42 + 37.68) × 1900)/(1000 × 0.81)]+1.0

$$V_{SC} = \left[\frac{A\,(R_d - SP50 + Ad)}{1000 \times CP50}\right] + 1.0$$

= 209 m^3

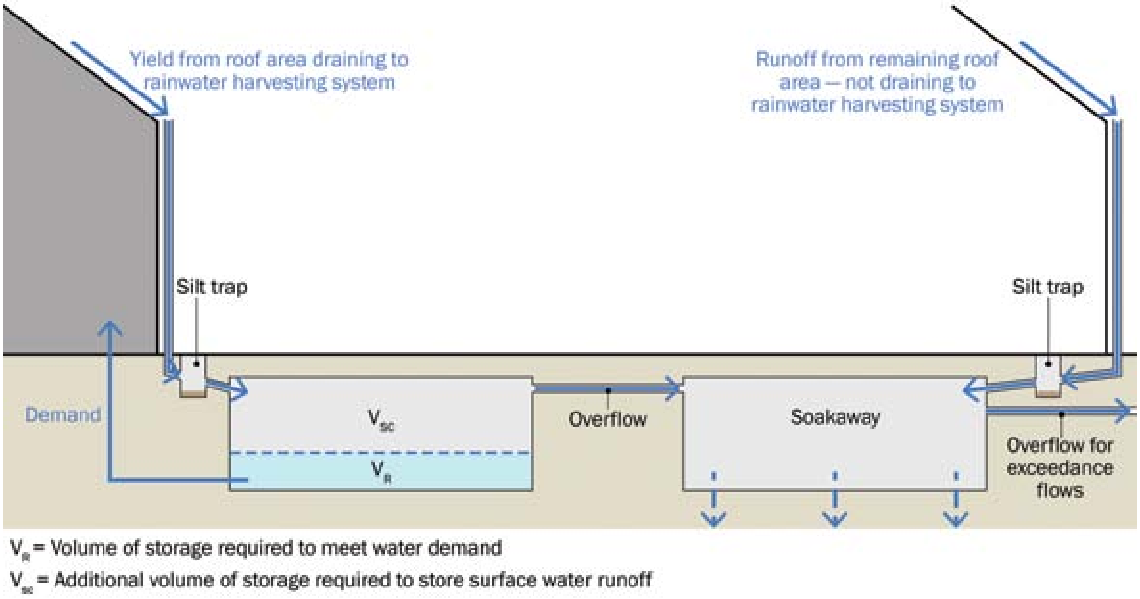


Figure C.10 Supermarket roof rainwater harvesting systems

C3 Lined pervious pavement

The pervious pavement serves the car park to the supermarket. The surface will be concrete block permeable paving in the car parking bays with an aggregate sub-base for surface water storage. The running aisles will be impermeable asphalt surfacing with normal road pavement construction below (ie no storage of water).

The car park is on a 1:200 slope in many places.

Structural design

Step 1 Estimate subgrade strength

The ground conditions at formation level comprise a clay material. Laboratory testing has determined that it has a plasticity index (PI) of 32%. From **Table 20.4** (**Section 20.9.3**) the guideline equilibrium CBR value for pervious surfaces is 3% (a plasticity index of 32% lies between two values so use the CBR for a PI of 30%). The subgrade CBR value will require confirmation by site testing when the subgrade is exposed during construction.

Step 2 Determine loading category

The site is a large car park that is trafficked mainly by cars or light commercial vehicles. There may be HGVs that end up turning or parking in the car park. The site is therefore classified as site category 5 (**Table 20.5, Section 20.9.4**).

Step 3 Determine construction thickness

The construction thickness requirements are taken from **Table 20.10** (**Section 20.9.6**) for traffic category 5, as follows:

- 80 mm concrete permeable pavers
- 50 mm bedding layer 2/6.3 aggregate
- 100 mm hydraulically bound coarse-graded aggregate or 70 mm AC32 asphalt concrete
- 150 mm sub-base CGA, which will also act as the water storage layer in the hydraulic design below.

The CBR is 3% and therefore subgrade improvement is required that is 225 mm thick. In this case, the improvement layer will be provided using an additional depth of CGA material to provide extra storage capacity.

Alternative surfacing materials in the parking bays could comprise:

- porous asphalt (**Table 20.8, Section 20.9.6**) which would mean a requirement for:
  - 160 mm porous asphalt
  - 150 mm sub-base CGA
  - 225 mm subgrade improvement layer (use CGA)
- porous concrete (**Table 20.9, Section 20.9.6**) which would mean a requirement for:
  - 150 mm plain porous concrete
  - 300 mm sub-base CGA
  - 225 mm subgrade improvement layer (use CGA).

Step 4 Hydraulic design

The pavement needs to be designed to store the 1:100 year event. The car park covers an area of 35,000 m^2 and the aisles (ie impermeable areas) comprise 40% of the total parking area.

The estimated total storage for the whole development site is 16,000 m^3 (**Section C.4.1, Step 2**).

The total impermeable area is 22 ha (**Table C.10**).

Therefore the storage required is 16,000 × (3.5/22) = 2545 m^3

The porosity of the sub-base is assumed to be 0.3 for materials meeting the specification in **Table 20.14** (**Section 20.11.4**).

The aisles will drain onto the parking bays as far as possible, and at 40% of the overall area, this meets the limiting ratio of 2:1 impermeable to permeable.

Depth of sub-base = volume of storage required/(area of parking bays × porosity of sub-base)

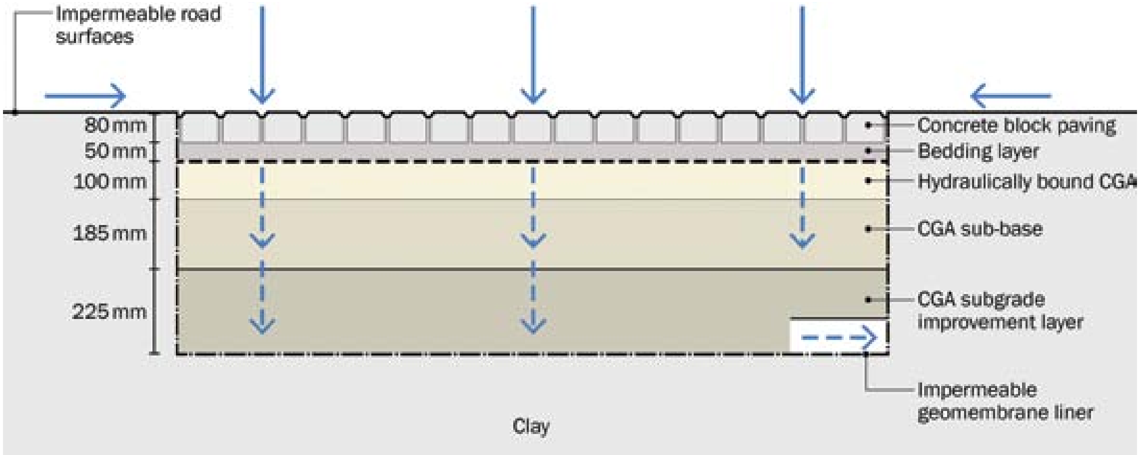
Depth of sub-base = 2545/(0.6 × 35,000 × 0.3) = 0.405 m or 405 mm.

As long as the subgrade improvement layer is provided using CGA material, the depth of the storage within the CGA will be sufficient. For block paving, the sub-base and subgrade improvement layer is a total of 375 mm thick and this will require increasing to 410 mm to meet the hydraulic requirements.

However, the site is on a 1:200 slope. The water will run to one end unless check dams or terracing are provided. The detailed design of this would depend on the detailed layout of the car park (**Section 20.5**) and is not covered here.

C4 Proprietary treatment system

The lorry parking and service area of the retail store site will drain to the detention basin. However, this basin is a surface component and part of the amenity space, so although the runoff will pass through several subsequent treatment components before discharge, it should not have visible pollution as this could damage the appearance of the detention basin. As a minimum therefore, the system should be designed to trap sediments and hydrocarbons.



Note

CGA = Coarse Graded Aggregate

Figure C.11 Supermarket lined permeable pavement

C4 Detention basin

The detention basin provides Interception and attenuation storage for the retail lorry service area behind the store, which has an area of 1.65 ha. It will be lined at a depth of 1.0 m to provide protection to underlying groundwater. The estimated design characteristics are:

100 year storage volume = 0.056 m^3/m^2 × 1.65 × 10,000 = 924 m^3.

Use initial estimate of 1200 m^3 to account for high impermeability of service area relative to rest of site.

100 year greenfield runoff rate = 1.65 × 10,000 × 0.00078 l/s/m^2 = 13 l/s (see **Table C.9**)

Step 1 Check the dimensions of the basin

If the area available for the basin is 1200 m^2 (width: 20 m, length: 60 m), with side slopes of 1:3, then:

TABLE C.20 Retail area detention basin area:depth profile

Layer	W (m)	L (m)	Area (m^2)	Depth from the ground surface (m)	Total excavated volume in layer (m^3)
Layer 1 (top)	20.00	60.00	1200	0.000	
Layer 2	19.25	59.25	1141	0.125	218
Layer 3	18.50	58.50	1082	0.250	424
Layer 4	17.00	57.00	969	0.500	681
Layer 5	14.00	54.00	756	1.000	1112
Layer 6	11.00	51.00	561	1.500	1441
Layer 7 (deepest)	8.00	48.00	384	2.000	1677

Therefore, the 100 year volume would be stored at a depth of approximately 1 m, which is acceptable.

Step 2 Check required outfall orifice size

Using **Equation 28.1** (**Section 28.5.2**) as follows:

$$Q = C_d \, A_o \sqrt{2gh}$$

where:

Q = orifice discharge rate, m^3/s

$C_d = 0.6$

A_o = area of orifice, m^2

h = 1.0 m

g = 9.81 m/s^2

Diameter of orifice to restrict the flow to the 1:100 year greenfield flow (13 l/s) is approximately 80 mm.

Step 3 Check maximum velocities and residence times for treatment

For a 20 mm/h 1:1 year, 15 minute rainfall event and a runoff factor of 0.9, the rate of runoff is 82.5 l/s.

Assuming this event is distributed over the base width of the detention basin:

Assume 11 m width – from calculated dimensions at 1.5 m depth below ground surface = 1.0 m plus a 0.5 m freeboard plus landscaping allowance. (Note: this could be reduced to 0.3 m in final design).

Assume slope of basin from inlet to outlet is 1:100, ie 0.01.

Assume Manning's roughness coefficient from below grass flow is 0.35, then using Manning's equation (**Equation 24.12, Section 24.11.1**):

TABLE C.21 Retail area detention basin depth:flow relationship for water quality

d (mm)	V (m/s)	Q (l/s)
20	0.021	5.473
40	0.033	17.377
60	0.044	34.156
80	0.053	55.169
100	0.062	80.022
120	0.070	108.437

Therefore, at a flow rate of 82.5 l/s, the depth of flow will be approximately 100 mm and the velocity will be approximately 0.06 m/s which is acceptable (**Section 17.4.1** for conveyance swale treatment design).

Assuming the flow path length at a depth of just over 1 m, is approximately 54 m (**Table C.20**), and the flow velocity is approximately 0.06 m/s, then the residence time = 54/0.06 = 15 minutes (which is greater than 9 minutes, therefore sufficient).

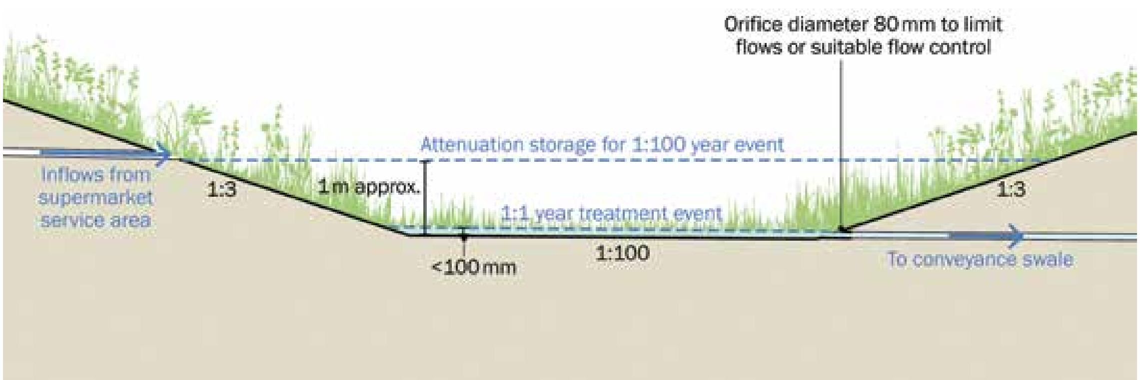


Figure C.12 Supermarket detention basin

Step 4 Landscape design

Once the volume and general water depths have been determined, the precise landscape form and planting in the basin will be developed by the landscape architect and ecologists to meet the amenity and biodiversity objectives. The planting could include trees and shrubs to support specific bird species.

C.5.4 Industrial area (D)

D1 Filter strip

The filter strip provides the first level of treatment for the runoff from the lorry park, and operates as pre-treatment for the filter drain. It is lined at a depth of 1 m to ensure adequate groundwater protection. Chapter 15 gives details for designing filter strips. The filter strip enables pollutants (particularly oils and heavy metals) to be easily seen and trapped early in the treatment train. There is space available for a 5 m wide strip on one side of the lorry park where the levels on the surface fall towards the area proposed for the filter strip. A schematic of the proposed filter strip is shown in Figure C.13 and design details are given in Table C.22.

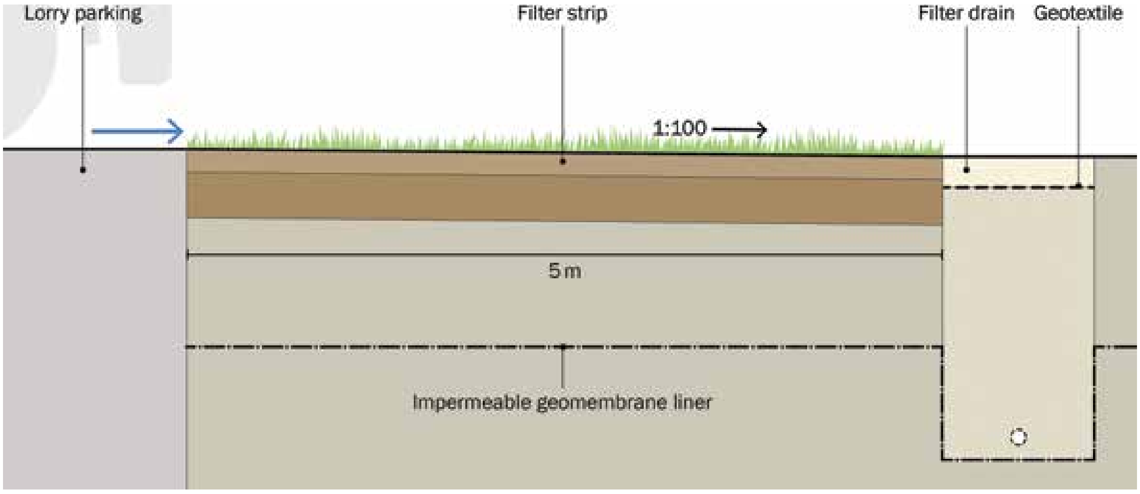


Figure C.13 Filter strip (and downstream filter drain) serving the lorry park

Assuming a time of concentration (critical event duration) of 15 minutes, the rainfall intensity for the 1:1 year event is 20 mm/hr. A runoff factor of 0.9 is also assumed.

TABLE C.22 Filter strip design data

Lorry park area	0.85 ha
Q for 1:1 year assuming a runoff coefficient of 90%	$0.020/3600 \times 0.85 \times 10^4 \times 0.9 = 0.0425$ m³/s
Width of filter strip (ie length of edge of lorry parking area)	350 m
Length (in direction of flow)	5 m
Manning's "n" used	0.35 (for below grass flow)
Slope	1:100 (0.01)

The contributing area is < 5 × the area of the filter strip, therefore adequate Interception can be assumed (Table 24.6).

Step 1 Check flow depth and velocity for 1:1 year event

From Equation 15.1:

$$V = \frac{d^{2/3} S^{1/2}}{n}$$

V = mean cross-sectional flow velocity (m/s)

d = depth of flow (m)

S = longitudinal slope of filter strip (ie in the direction of flow) (m/m)

n = Manning's "n" roughness coefficient ($m^{-1/3}s$)

Assuming a Manning's "n" value for below grass flow of 0.35, gives the following results:

TABLE C.23 Industrial area filter strip depth:flow relationship for water quality

d (mm)	V (m/s)	Q (l/s)	Q (m^3/s)
5	0.008	15	0.015
10	0.013	46	0.046
15	0.017	91	0.091
20	0.021	147	0.147
25	0.024	214	0.214
30	0.028	290	0.290
35	0.031	374	0.374

This demonstrates that the 1:1 year treatment event will flow at a depth of < 15 mm (ie below the height of the vegetation), with a velocity of less than 0.3 m. This means that design criteria for the treatment event are met.

Step 2 Check residence time for 1:1 year event

The flow velocity is approximately 0.01 m/s, therefore the time to travel 5 m filter strip is just over 8 minutes. This is just acceptable, but if there is scope to increase the width of strip that would be better.

Step 3 Check flow velocities for more extreme events

A check is required that velocities remain below 1.5 m/s for extreme flows to prevent erosion.

Assuming a rainfall intensity of 150 mm/hr for the 1:100 year event:

Q = 0.150/3600 × 0.85 × 10^4 × 0.9 ×1000 = 323 l/s which meets the design criteria of < 1.5 m/s for the extreme event.

D2 Filter drain

The proposed filter drain is 1 m wide and 2 m deep, as shown in **Figure C.14**.

The ground profile adjacent to the filter drain will be such as to direct flows in excess of the 1:10 year storm towards downstream components. This will also act as a failsafe mechanism should lack of maintenance result in the drain becoming blocked.

The sand/pea gravel layer above the filter material will also act as treatment in preventing ingress of fine material from the car park. This layer can be removed and replaced together with the underlying geotextile, if required.

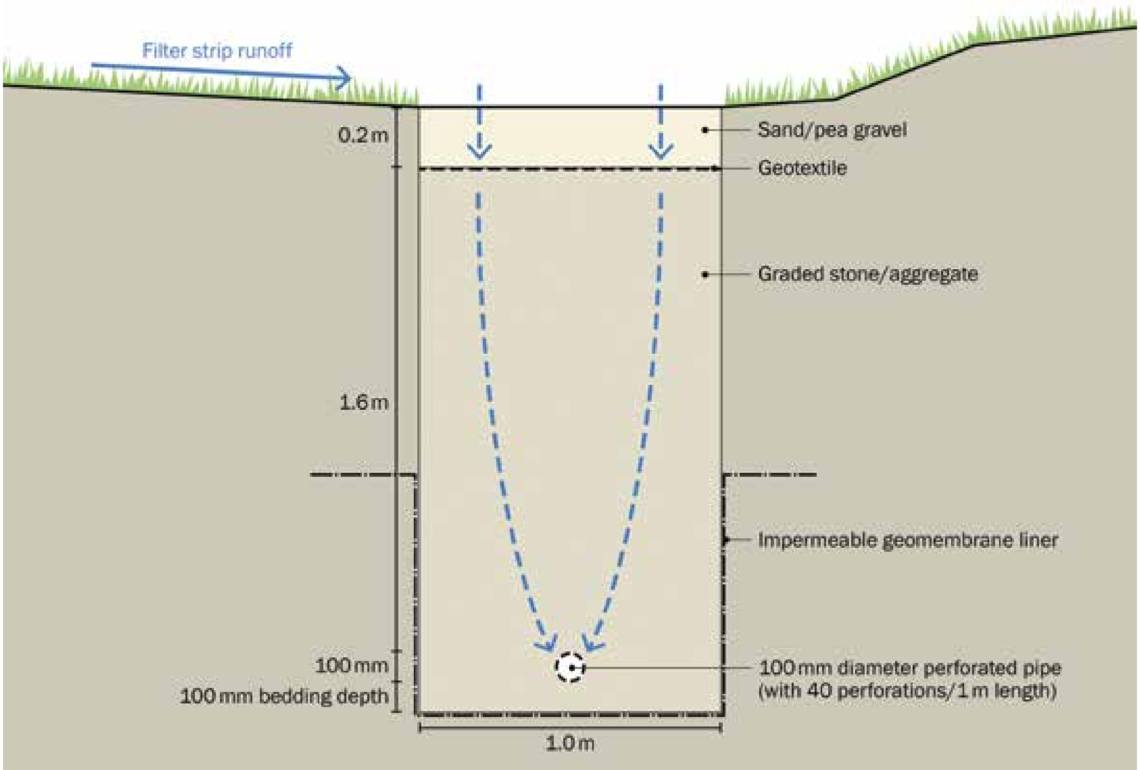


Figure C.14 Lorry park filter drain

The filter drain characteristics are:

Length of filter drain	350	m
Depth of filter drain	2	m
Width of filter drain	1	m
Porosity of filter aggregate	0.3	
Slope on filter drain base, i	0.02	m/m
Permeability, k of filter aggregate	0.0005	m/s

Using the same inflows as for the filter strip (D1):

1 year runoff rate	0.043	m^3/s
10 year runoff rate	0.151	m^3/s
30 year runoff rate	0.213	m^3/s
100 year runoff rate	0.323	m^3/s

Step 1 Estimate the rate of flow from the point of entry to the receiving perforated pipe, through the gravel filter media

Using Darcy's Law, as given in Equation 20.2 (Section 20.5.1):

$$Q = A\,k\,i$$

where:

Q = flow capacity of sub-base (m^3/s)

A = cross-sectional flow area, ie height × width of sub-base through which water is flowing (m^2)

k = coefficient of permeability of sub-base (m/s)

i = hydraulic gradient (m/m) (the hydraulic gradient is the head of water driving the flow. It is generally accepted that for vertical flow over short distances i = 1)

Q = 350 × 1 × 0.0005 × 1 = 0.175 m^3/s which represents somewhere between a 1:10 and a 1:30 year event, which is acceptable.

Step 2 Check capacity of perforated pipe collection system

Using **Equation 28.1** (**Section 28.5.2**) to represent the orifice flow through a perforation as follows:

$$Q = C_d\, A_o \sqrt{2gh}$$

Where:

Q = Orifice discharge rate, m^3/s

C_d = Coefficient of discharge, m (0.6 if material is thinner than orifice diameter; 0.8 if material is thicker than orifice diameter, 0.92 if edges of orifice are rounded)

A_o = area of orifice, m^2

h = hydraulic head, m

g = 9.81 m/s^2

This gives the following:

C_d	0.6
Perforation diameter	5 mm
Perforation radius	2.5 mm
Perforation area	19.6375 mm^2
	1.96375 × 10−5 m^2
Head – assume a minimum of the diameter of the pipe	0.1 m
Number of perforations	40 per m length of pipe
Total number of perforations	= 350 × 40 =14,000
Q per perforation	1.65039 × 10−5 m^3/s
Q total	0.23 m^3/s

This flow rate exceeds the rate of flow through the filter aggregate, therefore the design is acceptable. Standard design tables can then be used to check the capacity of the 100 mm diameter perforated pipe to carry the design flows.

D3 Underdrained swale

The swale is draining the car park and delivery area for the industrial unit, together with the external service areas for the industrial site.

An underdrained swale has been agreed as an appropriate precautionary approach, as it means that there is a low risk of silts being transferred downstream and it delivers a high level of treatment.

The swale drains an area of 4.1 ha. The swale lies adjacent to the road and will be inaccessible from that side. Therefore a vertical roadside edge is acceptable, with a 1:3 slope on the industrial site side.

The swale is 600 m long, 3 m wide and has a longitudinal slope of 1:100 (0.01).

An underdrained swale (without lining) can be assumed to deliver Interception for 25x its area which is > 4.1 ha.

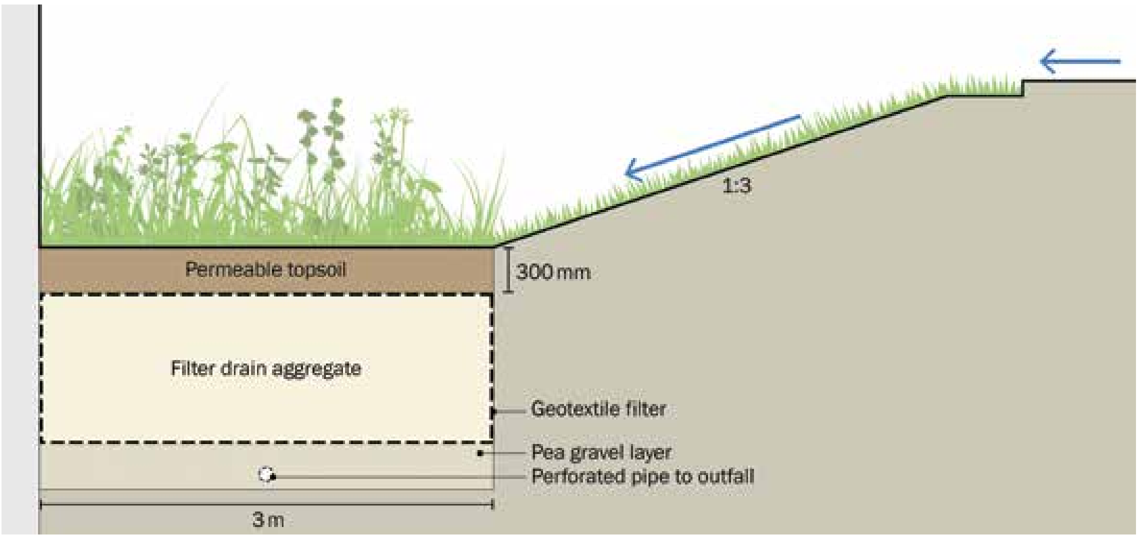


Figure C.15 Industrial site underdrained swale

Step 1 Calculate runoff rates into the swale

Runoff area: 41,000 m^2

Runoff factor: 0.9

Rainfall intensity	For 1:1 year, 15 minute event: 20 mm/h
	For 1:10 year, 15 minute event: 64 mm/h
	For 1:30 year, 15 minute event: 100 mm/h
	For 1:100 year, 15 minute event: 150 mm/h
Runoff rates:	$= A \times 0.9 \times i$
	For 1:1 year event = 0.205 m^3/s
	For 1:10 year event = 0.656 m^3/s
	For 1:30 year event = 1.025 m^3/s
	For 1:100 year event = 1.538 m^3/s

Step 2 Calculate flow rate from swale to filter drain

Permeability of the filter aggregate = 0.0005 m/s

$$Q = 600 \times 3 \times 0.0005 = 0.9 \text{ m}^3/\text{s}$$

This is almost a 1:30 year event, which is acceptable.

Step 3 Check perforated pipe specification is suitable to convey flow

See equivalent calculations in filter drain example.

Step 4 Check non-erosive velocities for extreme events

Using Manning's equation

$$Q = \frac{A\, R^{2/3}\, S^{1/2}}{n}$$

Where

below grass flow, n = 0.35

at depth 200 mm, n = 0.1

at depth 400 mm, n = 0.04

Gives:

TABLE C.24 Industrial site underdrained swale depth: flow relationship

d (mm)	V (m/s)	Q (m^3/s)
50	0.039	0.006
60	0.044	0.008
70	0.049	0.010
80	0.053	0.013
90	0.057	0.015
100	0.062	0.018
150	0.282	0.127
200	0.342	0.205
250	0.397	0.298
300	0.448	0.403
325	0.591	0.576
350	0.828	0.869
400	1.357	1.629
450	1.468	1.982

The 1:100 year flow rate has a velocity below 1.5 m/s, which is acceptable.

The runoff rates and depths would need confirmation via modelling at detailed design stage.

D4 Wetland area

A small wetland area is required to provide additional treatment of the industrial area runoff before discharge to the amenity pond. A rough rule of thumb for sizing a pond/wetland for treatment is to make sure that the volume of permanent water is equal to the volume of water that requires treatment (known as the treatment volume).

Area available for the wetland = 800 m^2

Assume runoff factor = 0.8

Combined lorry park and factory hard standing area = 4.95 ha (this is 0.85 lorry park area plus 4.1 factory hard standing area)

Volume of water requiring treatment (known as the treatment volume) = $4.95 \times 10^4 \times 15 \times 10^{-3} \times 0.8 = 600$ m^3

(where 15 mm is the upper limit rainfall depth recommended in **Section 23.5**)

Average depth of permanent pool = 600/800 = 0.75 m, which is acceptable.

In order to protect wetland planting, the attenuation storage depth (above the permanent water level) was limited to 0.4 m, which provides a maximum attenuation storage volume of 320 m^3 for the component.

C.5.5 Strategic site SuDS components

S1 Strategic conveyance swale running north–south through the site

This swale drains excess flows from the residential zone, the civic street zone and the supermarket – together with all the runoff from the roads.

Assume:

- residential area: infiltrates to 1:10 year
- civic street area: infiltrates to 1:10 year
- supermarket area: managed to 1:100 year greenfield
- roads: unmanaged

For 1:30 year event:

(Note that these are relatively crude conservative estimates for initial design purposes.)

For residential and civic street areas (ie areas A and B)

- rainfall intensity = 100 mm/h
- runoff factor = 0.8

$Q = 100 \times 10^{-3} \times 0.8 \times (6.5 + 4.5) \times 10^4/3600 = 2.44\ m^3/s$

For supermarket area (area C)

Runoff controlled to greenfield runoff rates (see Table C.11) = 0.033 m^3/s

For roads

- rainfall intensity = 100 mm/h
- runoff factor = 0.9

$Q = 100 \times 10^{-3} \times 0.9 \times 1.5 \times 10^4/3600 = 0.375\ m^3/s$

Estimated total flow to swale for 1:30 year event = 2.44 + 0.033 + 0.375 = 2.85 m^3/s

This would need confirmation via modelling at detailed design stage.

A 3 m width of swale over 1000 m = 3000 m^2. Average slope = 0.01

Interception delivery = $3000 \times 25 \times 10^{-4} = 7.5$ ha

This is acceptable for retail service area (1.65 ha) and impermeable areas draining to permeable pavement (1.4 ha).

Step 1 Check capacity of the swale for the 30 year event

Assume average Manning's n = 0.15 for high flows

Assume average flow width = 6 m

(This takes account of flow across the side slopes. At a 1 m depth of flow, with side slopes of 3:1, the effective width would be 3 + (2 × 3 × 1) = 9 m, which gives an average width of (3 + 9)/2 = 6 m)

Using Manning's equation gives:

TABLE C.25 Strategic swale depth:flow relationship for above grass flows

d (mm)	V (m/s)	Q (m3/s)
50	0.090	0.03
100	0.144	0.09
150	0.188	0.17
200	0.228	0.27
250	0.265	0.40
300	0.299	0.54
350	0.331	0.70
400	0.362	0.87
450	0.391	1.06
500	0.420	1.26
600	0.474	1.71
700	0.526	2.21
800	0.575	2.76
900	0.621	3.36
1000	0.667	4.00

Therefore, the depth of flow for the 1:30 year event would be approximately 850 mm, at a velocity of 0.6 m/s, which meets the design criteria

Step 2 Check treatment performance of the swale for the 1:1 year event

Assume Manning's "n" for below grass flow = 0.35, flow width = 3 m

No contribution from sub-catchments A and B		
Greenfield runoff from C	0.012	m^3/s
Greenfield runoff from roads	0.005	m^3/s
Total 1:1 year runoff	0.017	m^3/s

TABLE C.26 Strategic swale depth:flow relationship for below grass flows

d (mm)	V (m/s)	Q (m^3/s)
20	0.021	0.001
40	0.033	0.004
60	0.044	0.008
80	0.053	0.013
100	0.062	0.018

This gives a flow depth of approximately 95 mm at a velocity of < 0.3 m/s, which meets the design criteria.

The swale length is over 1000 m, therefore the residence time will be substantially greater than 18 minutes (1000 m / 0.06 m/s > 200 minutes), and is therefore acceptable.

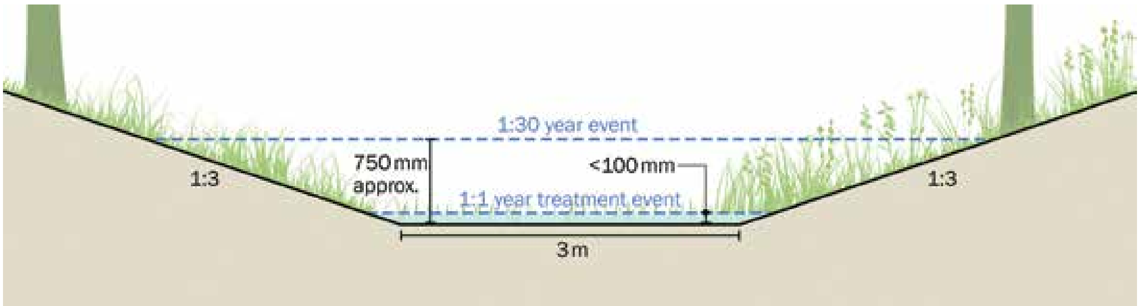


Figure C.16 Strategic site conveyance swale

S2 Strategic amenity pond

This provides final stage polishing and the remaining attenuation storage, and also high value amenity and biodiversity benefits. The need for the pond base to be made suitably impermeable to retain permanent water levels and to prevent groundwater from reducing the available attenuation storage in the pond should be given full consideration as part of the detailed design.

Step 1 Estimate the required attenuation storage

A rough estimate is made of the remaining storage likely to be required in the pond. This would need confirmation via modelling at detailed design stage.

Sub-catchment	Area (ha)	Required total 1:100 year attenuation storage volume (m^3)	Contributions to attenuation storage reduction	Additional attenuation storage required for 1:100 year event in the downstream pond over and above that delivered by upstream components (m^3)
From Table C.12				
A	6.5	3624	Infiltration up to 1:10 year event	Using growth curve factors in Table 24.2 for hydrometric region 5 (1.65 for 10 year event, 3.56 for 100 year event): Storage required = 3624 – (1.65/3.56) × 3624 = 1944 m^3
B	4.5	2509	Infiltration to 1:10 year event	Using approach above: Storage required = 2509 – (1.65/3.56) × 2509 = 1346 m^3
C	6.2	3456	Full attenuation in subcatchment	Storage required = 0 m^3
D	5.6[1]	3122	Roof runoff is fully attenuated Attenuation volume required for hardstanding area = 0.056 × 4.95 = 2760 m^3	Assume: 200 m^3 provided in subsurface filter drain 700 m^3 provided in above ground swale 350 m^3 provided above wetland area Storage required = 2760 – (200 + 700 + 350) = 1510 m^3
E	4.4	2453	Assume 40% of subcatchment is attenuated to 1:100 year	Storage required = 0.6 × 2453 = 1472 m^3
Roads	1.5	836		Storage required = 836 m^3

Note

1 This area is the sum of 4.95 ha hardstanding 0.65 ha roof area

Total attenuation storage required in the pond = 1944 + 1346 + 0 + 1510 + 1472 + 836 = 7108 m^3

Section 24.9.4 suggests that an additional 25% should be added to initial storage volume estimates to allow for lack of inclusion of head discharge relationships.

Therefore total attenuation storage required in the pond = 8885 m^3

For a uniform pond area of about 5000 m^2, this would mean 1.8 m depth. Based on a bank slope of 1 in 5, however, the actual depth will be around 1.5 m.

This is indicated as acceptable for this scale of event by the site health and safety risk assessment.

Step 2 Calculate treatment volume

A rough rule of thumb for sizing a pond for treatment is to make sure the volume of permanent water in the pond is equal to the volume of water that requires treatment (known as the treatment volume).

For a 1:1 year return period (required for treatment) areas A, B and the supermarket roof would not be contributing. Therefore:

Total area = 31.1 – (6.5 + 4.5 + 0.9) = 19.2 ha

If assume

- rainfall depth that requires treatment is 15 mm (based on maximum recommended treatment volume, **Section 23.5**)
- average runoff factor = 0.5

Treatment volume = $19.2 \times 10^4 \times 15 \times 10^{-3} \times 0.5 = 1440$ m^3

Based on a pond area of about 5000 m^2, the average depth would be approximately 0.3 m (see **Figure C.11**).

Step 3 Confirm spill levels to Long-Term Storage

To adequately control the volumes of runoff from the site, a spill will be required into a Long-Term Storage area (probably the adjacent sports pitches), or else the runoff rate will need constraining further and the attenuation storage volume increased.

A detailed model will be required to determine which option would be preferable with respect to the performance of the system.

The depth of inundation of the estimated 2640 m^3 of Long-Term Storage (see **Section C.4.1, Step 3**) would be 0.2 m, if spread over 2 × 7000 m^2 football pitches.

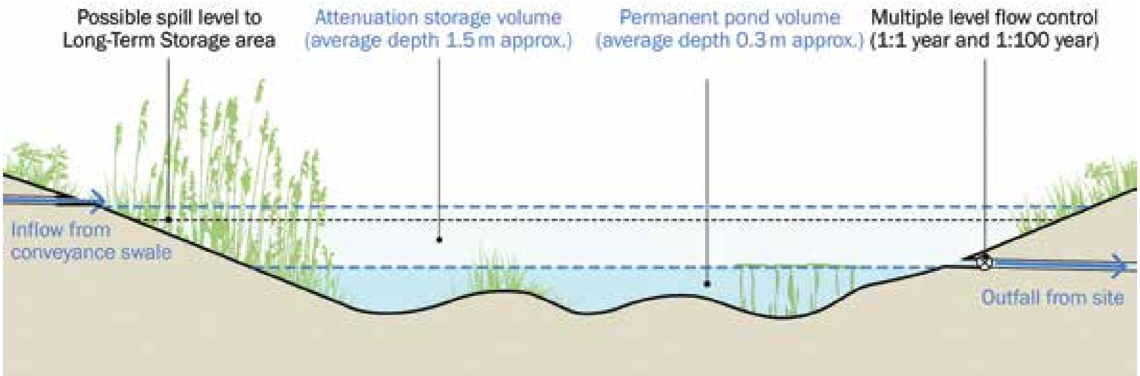


Figure C.17 Strategic amenity pond

C.5.6 Detailed system sizing

A detailed model of the contributing catchment and drainage system is required in order to check that all criteria have been achieved. The calculations above provide initial sizing information and allow a first estimate to be modelled, which can then be refined to achieve the required results. The particular checks that should now be made with the detailed model are as follows:

- greenfield discharge rates achieved for 1:1, 1:10 and 1:100 year
- no unplanned flooding on the site for the 1:30 year critical site event (short duration, high intensity event)
- no flooding of property from the site drainage system for the 1:100 year critical site event (short duration, high intensity event)
- no flooding of property for key "blockage" scenarios
- the possible impact and performance of the pond for the maximum 1:100 year river level for a range of return period events (a joint probability analysis may be required depending on this assessment).

C.6 REFERENCES

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This guidance covers the planning, design, construction and maintenance of Sustainable Drainage Systems (SuDS) to assist with their effective implementation within both new and existing developments. It looks at how to maximise amenity and biodiversity benefits, and deliver the key objectives of managing flood risk and water quality. There is also supporting information covering topics such as materials, landscape design, maintenance, community engagement and costs and benefits.

The information presented in this publication is a compendium of good practice, based on existing guidance and research both in the UK and internationally, and the practical experience of the authors, project steering group and industry.

This guidance provides the framework for designing SuDS with confidence and to maximise benefits. Its contents are relevant for a wide-range of professions and roles and it highlights that through engagement and collaboration SuDS can be integrated into the design of urban areas, to create high quality places for future generations.

The key message is that SuDS should be designed to maximise the opportunities and benefits that can be secured from surface water management.

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